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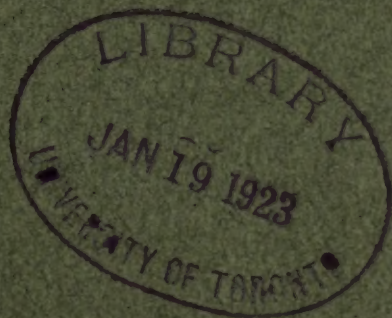
BUREAU OF MINES

H. FOSTER BAIN, DIRECTOR

ELECTRIC BRASS FURNACE
PRACTICE

BY

H. W. GILLETT and E. L. MACK



WASHINGTON
GOVERNMENT PRINTING OFFICE

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ALBERT D. HALL, BUILDING

BUREAU OF MINES

U. S. GOVERNMENT PRINTING OFFICE

ELECTRIC BRASS FURNACE

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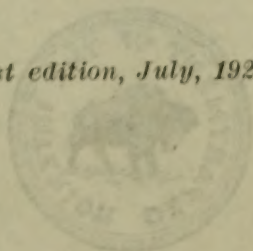
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PREFACE.

The Federal Bureau of Mines began its work on the reduction of metal losses in melting nonferrous metals and the improvement of conditions affecting the health and safety of the workmen in the nonferrous industries in 1911.

The electric furnace at once suggested itself as a promising means of reducing metal loss and improving working conditions. No electric furnace suitable for melting brass was then in existence. The bureau promptly began to study the problem experimentally and to encourage brass melters, electric-furnace designers, and electric generating stations to study it also.

Since that time a great amount of experimental work on, and commercial development of, electric brass furnaces has been done by different groups commercially interested, as well as by the bureau, with the result that electric melting has been found to give the advantages expected, and to be industrially desirable; it is acknowledged to-day to be usually the best and cheapest way to melt brass and many other nonferrous alloys. Apparently it is only a matter of a few years before more brass will be melted by electricity than by fuel. The electric furnace bids fair to become the standard type for brass melting.

The present report is published to record the progress so far made in melting brass electrically; to aid the plants which have not yet taken up such melting by pointing out the types of furnaces available, describing their performance and indicating their possibilities and their limitations; and to encourage further experimentation with and the development and installation of electric brass furnaces.

ELECTRIC BRASS FURNACE PRACTICE.

By H. W. GILLETT and E. L. MACK.

INTRODUCTION.

HISTORICAL REVIEW.

Prior to 1911 the literature on melting brass by electricity consisted entirely—save for some suggestions made in patent literature but not actually worked out—of a few observations by farseeing men¹ on the theoretical advantages of melting brass and other nonferrous alloys in electric furnaces.

Roeber was the first to see and clearly state the possible advantages of the electric furnace in brass melting. The same factors that make it desirable to manufacture special steels in the electric furnace rather than in crucibles, he declared, apply to brass as well. He pointed out the possibility of using larger melting units, of eliminating crucible cost, of readily controlling the purity of the product, and of nearly eliminating the loss of zinc. "The replacement of the old crucible process is sure to come," he said; "perhaps it will come in two years, but it will, necessarily, in ten years. . . . The inevitable advance along this industrial line will have great influence in the metal world and will also provide, in large cities, a new kind of load for the central station."

The years 1905 to 1910 may be termed the purely theoretical period of the development of the electric brass furnace, though the Conley furnace was tried out experimentally about 1910 and a few heats were made in an induction furnace.²

In December, 1911, the American Chemical Society held a symposium on mineral wastes, at which Bassett³ discussed the zinc losses that attend making brass in fuel-fired furnaces.

¹ Roeber, E. F., *Manufacture of brass in the electric furnace*: *Electrochem. and Met. Ind.*, vol. 3, 1905, p. 4; Moldenke, R., *Electric furnaces for the foundry*: *Electrochem. and Met. Ind.*, vol. 1, 1909, p. 160; Krom, L. J., *Development of melting furnaces*: *Metal Ind.*, vol. 7, 1909, p. 287; Bragg, C. T., *Modern brass-foundry progress*: *Trans. Am. Brass Founders' Assn.*, vol. 4, 1910, p. 43; Richards, J. W., *Electric furnaces in nonferrous metallurgy*: *Met. and Chem. Eng.*, vol. 8, 1910, p. 233.

² Rowlands, T., *Induction-furnace progress*: *Trans. Am. Electrochem. Soc.*, vol. 17, 1910, p. 103.

³ Bassett, W. H., *Zinc losses*: *Jour. Ind. and Eng. Chem.*, vol. 4, 1912, p. 164.

In the discussion of this paper, Parsons⁴ pointed out that in a closed electric furnace zinc losses should be minimized, and said that the Bureau of Mines was planning to take up the question of electric furnaces for melting nonferrous alloys.

About this time several electric furnaces⁵ were advertised, advocated, or suggested for melting brass, seemingly either on the basis of tests with zinc, on the basis of a run or two on copper, or on even less experience, except for the Hering furnace.

None of these furnaces are now prominent in the brass industry, although the final outgrowth of Clamer's work with the Hering furnace was the Ajax-Wyatt furnace, a type of great commercial importance.

Bensel⁶ gave in 1912 the results on a few runs on brass in a small experimental laboratory furnace.

Various small-scale tests were made with different types of furnaces by different experimenters in 1913 without any notable progress resulting. The period 1911 to 1913 may be termed the early, small-scale experimental period of the electric brass furnace.

Late in 1913, in 1914 and 1915, experiments began with fair-sized furnaces under foundry conditions, the Rennerfelt being tested in Sweden, the Helberger, Hering, and two early forms of the Baily, the Ajax-Wyatt, a Snyder crucible lift-out, and a Hoskins crucible lift-out, in the United States. Of these only the Rennerfelt and Ajax-Wyatt survived. The years 1913 to 1915 comprised the period of early larger-scale experiments.

Early in 1916 the Ajax-Wyatt reached a close approximation to its present form and began to melt brass commercially. At the same time a small Snyder direct-arc furnace gave promising results on leaded bearing-bronze and was the precursor of an installation of two 1-ton Snyder furnaces which began commercial production later in the year.

The present form of the Baily furnace began to melt commercially "Lumen" metal, an alloy containing 85 per cent zinc, with occasional test runs on brass. The General Electric furnace was

⁴ Parsons, C. L., Discussion: *Metal Ind.*, vol. 10, 1912, pp. 240-241; see also Parsons, C. L., Notes on mineral wastes: *Bull.* 43, Bureau of Mines, 1912, p. 20.

⁵ Anonymous, The Helberger furnace: *Metal Ind.*, vol. 9, 1911, p. 212; advertisements; see also Wile, R. S., An electric furnace for treatment of tin dross, concentrates, and other metallurgical work: *Met. and Chem. Eng.*, vol. 10, 1912, p. 495; Weeks, C. A., Melting nonferrous metals in an electric furnace: *Met. and Chem. Eng.*, vol. 9, 1911, p. 393; see also Hansen, C. A., Electric melting of copper and brass: *Trans. Am. Inst. of Metals*, vol. 6, 1912, p. 119; Clamer, G. H., and Hering, C., The electric furnace for brass melting: *Trans. Am. Inst. Metals*, vol. 6, 1912, p. 99; Thomson-Fitzgerald, F. A. J., A new electric resistance furnace: *Trans. Am. Electrochem. Soc.*, vol. 19, 1911, p. 283.

⁶ Bensel, F., Versuche zur Verminderung der Metallverluste beim Messingschmelzen: *Metallurgie*, vol. 9, 1912, p. 533. Abstracted in *Chem. Abs.*, vol. 6, 1912, p. 3256; *Jour. Soc. Chem. Ind.*, vol. 31, 1912, p. 879; *Journal Inst. Metals (British)*, vol. 8, 1912, p. 353; *Jour. Franklin Inst.*, vol. 175, 1913, p. 150.

melting on a semicommercial scale at Schenectady, and experimental melting was done with the Foley furnace.

In 1917 came the installation in this country of commercial Rennerfelt furnaces for brass and bronze, marked extension of the use of the Ajax-Wyatt and the Baily, a trial of the General Electric at a Chicago plant, and a foundry-scale test of a rocking furnace.

By the end of 1918 three types of furnaces—the Ajax-Wyatt, the Baily, and the rocking furnace—had forged ahead and were doing the bulk of the commercial electric-furnace melting.

Table 1 shows the number of active furnaces installed or being installed for melting brass and bronze on January 1, 1922.

TABLE 1.—*Electric furnaces in active commercial use or being installed for nonferrous alloys in the United States, Jan. 1, 1922.*

DIRECT-ARC FURNACES.

Make.	No.	User.	Alloy.	Capacity tons per heat per furnace.	Total capacity tons.	Total kw. rating.	Total kw.
Heroult <i>a</i>	2	Driver-Harris Co., Harrison, N. J.	Nickel alloys....	2	4	800	<i>b</i> 1,600
Greaves-Etchell.....	1	Hoskins Manufacturing Co., Detroit, Mich.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	300	<i>b</i> 300
Snyder.....	1	Monel Metal Products Co., Bayonne, N. J. ^c	Monel.....	$\frac{1}{2}$	$\frac{1}{2}$	100	<i>d</i> 100
	1	Chrobaltic Tool Co., Chicago, Ill.	Cobalt-chromium.	$\frac{1}{2}$	$\frac{1}{2}$	60	<i>d</i> 60
	3	Haynes Stellite Co., Kokomo, Ind.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	60	<i>d</i> 240
	2	Chicago Bearing Metal Co., Chicago, Ill.	Leaded bronze..	1	2	400	<i>e</i> 800
Total.....	10	Number of users, 6.		.....	7.5	.....	2,100

STATIONARY INDIRECT-ARC FURNACES.

Rennerfelt <i>f</i>	<i>g</i> 1	Chicago Bearing Metal Co., Chicago, Ill.	Leaded bronze..	1	1	300	<i>h</i> 300
	1	U. S. Mint, Philadelphia, Pa.	Bronze and silver	$\frac{1}{2}$	$\frac{1}{2}$	150	<i>i</i> 150
	1	do.....	do.....	1	1	300	<i>i</i> 300
	1	U. S. Mint, San Francisco, Calif.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	125	125
	1	Bausch Machine Tool Co., Springfield, Mass.	Hardeners for aluminum.	$\frac{1}{2}$	$\frac{1}{2}$	100	100
	1	Hardite Metals Co., Long Island City, N. Y.	Nickel-chromium.	$\frac{1}{2}$	$\frac{1}{2}$	150	150
	1	Gorham Manufacturing Co., Providence, R. I.	Silver.....	$\frac{1}{2}$	$\frac{1}{2}$	100	<i>h</i> 100
	1	Skagit Iron & Steel Co., Sedro Wooley, Calif.	Bronze.....	$\frac{1}{2}$	$\frac{1}{2}$	300	<i>h</i> 300

a Another Heroult furnace melting nickel alloys is installed at Hiram Walker Metal Products Co., Walkerville, Ontario, Canada.

b Three-phase automatic control.

c According to an editorial in *Foundry* (vol. 49, 1921, p. 583), a Moore furnace (size not given) has recently been ordered for the International Nickel Co., Huntington, W. Va., for melting Monel metal.

d Single phase.

e Single phase, automatic control.

f A $\frac{1}{2}$ -ton 100-kw. Rennerfelt for melting Monel, bronze, and brass up to 22 per cent zinc is installed at the Gerline Brass Foundry Co., Kalamazoo, Mich., but has not been in service for some time on account of power shortage.

g A second 1-ton Rennerfelt at this plant has been made over into a Re-pel-arc furnace.

h Two phase.

i Two phase; nose tilting and automatic control.

TABLE 1.—*Electric furnaces in active commercial use, etc.*—Continued.

STATIONARY INDIRECT-ARC FURNACES—Continued.

Make.	No.	User.	Alloy.	Capacity tons per heat per furnace.	Total capacity tons.	Total kw. rating.	kw.
Repel-arc f....	1	Chicago Bearing Metal Co., Chicago, Ill.	Leaded bronze..	1	1	450	k 450
	2	Crane Co., Chicago, Ill.	Monel and bronze	$\frac{3}{8}$	$\frac{3}{8}$	50	k 100
	1	Sandusky Foundry & Machine Co., Sandusky, Ohio.	Bronze.....	$\frac{3}{8}$	$\frac{3}{8}$	50	k 50
	1	Manning, Maxwell & Moore, Inc., Bridgeport, Conn.	do.....	$\frac{3}{8}$	$\frac{3}{8}$	50	k 50
	1	Bridgeport Brass Co., Bridgeport, Conn.	do.....	$\frac{3}{8}$	$\frac{3}{8}$	70	k 70
Total.....	14	Number of users, 11.			7.1		

MOVING INDIRECT-ARC FURNACES—SINGLE PHASE.¹

Detroit rocking.	2	Aluminum Manufacturing Co., Inc., Detroit, Mich.	Brass and bronze	1	2	300	ou
	2	American Bushing Corp. Marysville, Mich.	do.....	1	2	300	600
	2	American Manganese Bronze Co., Holmesburg, Pa.	do.....	1	2	300	600
	1	American Metal Products Co., Milwaukee, Wis.	Bronze.....	$\frac{1}{2}$	$\frac{1}{2}$	150	m 150
	1	Bethlehem Shipbuilding Co., Redington, Pa.	Brass and bronze	1	1	300	300
	5	C. B. Bohn Foundry Co., Detroit, Mich.	Brass, bronze, and aluminum	1	5	300	1,500
	2	Bound Brook Oilless Bearing Co., Bound Brook, N. J.	Bronze.....	$\frac{1}{2}$	1	150	300
	1	Bridgeport Brass Co., Bridgeport, Conn.	Bronze and copper.	1	1	300	300
	1	Chapman Valve Mfg. Co., Indian Orchard, Mass.	Brass and bronze	$\frac{1}{2}$	$\frac{1}{2}$	125	125
	4	Chase Metal Works, Waterbury, Conn.	Brass.....	1	4	300	1,200
	1	Cleveland Brass & Copper Rolling Mills, Cleveland, Ohio.	do.....	1	1	300	300
	so	Detroit Copper and Brass Rolling Mills, Detroit, Mich.	do.....	1	8	300	o 2,400
	1	Detroit Lubricator Co., Detroit, Mich.	Brass and bronze	1	1	300	m 300
	1	Ford Motor Co., Detroit, Mich.	do.....	1	1	300	300
	1	Ford Motor Co., River Rouge, Mich.	do.....	1	1	300	300
	2	General Aluminum & Brass Manufacturing Co., Detroit, Mich.	do.....	1	2	300	600
	1	General American Tank Car Corp., Chicago, Ill.	do.....	$\frac{1}{2}$	1	150	150
	1	Lumen Bearing Co., Buffalo, N. Y.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	150	p 150
	1	Hills, McCanna Co., Chicago, Ill.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	75	75
	2	Michigan Lubricator Co., Detroit, Mich.	do.....	1	2	300	600
	4	Michigan Smelting & Refining Co., Detroit, Mich.	do.....	1	4	300	1,200
	2	Mueller Metals Co., Port Huron, Mich.	Brass.....	1	2	300	600
	1	Oregon Brass Works, Portland, Oreg.	Brass and bronze	1	1	300	300
	1	do.....	do.....	$\frac{1}{2}$	$\frac{1}{2}$	150	150
	3	Parish Pool Co., Cleveland, Ohio.	do.....	1	3	300	q 900

¹ The repelling-arc furnace may be operated either as direct or indirect arc furnace.

k Three phase.

² A three-phase oscillating indirect-arc furnace, the Volta, has been tried out in a 1-ton 300-kw. size at the Transium Bronze Co., Niagara Falls, but that firm has ceased operations. A demonstration furnace is installed at The Fitzgerald Laboratories, Inc., Niagara Falls, N. Y. Three furnaces, of 1, $\frac{1}{2}$, and $\frac{1}{4}$ ton capacities have been ordered, but none are to be installed at once.

m Being installed.

n Six installed, two being installed.

o Direct pouring furnaces.

p Automatic control.

q Two direct pouring.

TABLE 1.—*Electric furnaces in active commercial use, etc.*—Continued.

MOVING INDIRECT—ARC FURNACES—SINGLE PHASE—Continued.

Make.	No.	User.	Alloy.	Capacity tons per heat per furnace.	Total capacity tons.	Total kw. rating.	Total kw.
inst.	1	Standard Underground Cable Co., Perth Amboy, N. J.	Brass and copper.	1½	1½	300	300
	1	Storm Peak Potash Co., Denver, Colo.	Aluminum.....	½	½	150	150
	3	Sherwood Brass Works, Detroit, Mich.	Brass and bronze	1	3	300	900
	1	Sarachan & Rosenthal, Inc., Rochester, N. Y.	Brass.....	1	1	300	300
	1	M. Smolensky Manufacturing Co., Cleveland, Ohio.	do.....	½	½	75	75
	1	White & Bros., Philadelphia, Pa.	Brass and bronze	1	1	300	30
	1	Wheeler Condenser & Engineering Co., Carteret, N. J.	do.....	1	1	300	300
TABLE	60	Number of users, 30.			54.4		16,325
Booths.....	3			1	3	300	900
	4			½	2	180	720
	25			¼	6½	125	9,125
	8			⅛	2	75	600
Total.....	40	Number of users of Booth furnaces, 35 to 40.			13½		5,345
Total for type..	100	Number of users of type, about 65.			67.6		21,670

REFLECTED-HEAT FURNACES.

Baily.....	1	Acheson Manufacturing Co., Rankin, Pa.	Brass and bronze	¾	¾	105	105
	1	Akron Bronze & Aluminum Co., Akron, Ohio.	do.....	¾	¾	105	105
	1	do.....	do.....	½	½	50	50
	1	Allis Manufacturing Co., Milwaukee, Wis.	do.....	½	½	50	50
	1	Alliance Brass & Bronze Co., Alliance, Ohio.	do.....	½	½	75	75
	1	American Hardware Corp., New Britain, Conn.	do.....	¾	¾	105	105
	1	Anaconda Copper Mining Co., Butte, Mont.	do.....	¾	¾	105	105
	1	Atlas Brass Works, Columbus, Ohio.	do.....	¾	¾	105	105
	1	Bagley & Sewall Co., Watertown, N. Y.	do.....	½	½	50	50
	2	Buick Motor Car Co., Flint, Mich.	do.....	¾	1½	105	210
	2	Burlington Brass Works, Burlington, Wis.	do.....	¾	1½	105	210
	2	Capitol Brass Co., Detroit, Mich.	do.....	¾	1½	105	210
	1	Chapman Valve Co., Springfield, Mass.	do.....	¾	¾	105	105
	1	Coppus Engineering & Equipment Co., Worcester, Mass.	do.....	¾	¾	105	105
	1	Claus Auto Gas Cock Co., Milwaukee, Wis.	do.....	½	½	75	75

† Direct pouring, standard furnace, lined for larger charge.

ra Since this table was put in type the Ford Motor Co. is reported to have ordered five more 1-ton 300 kw. Detroit rocking furnaces, all having automatic control.

* The number of furnaces of each size is given according to information supplied by the makers of the furnace. The number of active furnaces may be less, as it is impossible to check up the full list of users, because it is not given out by the makers. Among the users are Bridgeport Brass Co., Bridgeport, Conn.; Cleveland Brass Co., Cleveland, Ohio; Dearborn Brass Co., Cedar Rapids, Iowa; Dallas City Foundry Co., Dallas City, Ill.; Fulton-Harwood Brass Works, South Bend, Ind.; National Bronze and Aluminum Foundry, Cleveland, Ohio; Michigan Smelting and Refining Co., Detroit, Mich.; Muskegon Aluminum Foundry Co., Muskegon, Mich.; Yale & Towne, Stamford, Conn.; Hill Pump Valve Co., Chicago, Ill.; Nordyke & Marmon Co., Indianapolis, Ind.; Prime Manufacturing Co., Milwaukee, Wis. Some of the Booth furnaces have automatic control.

TABLE 1.—*Electric furnaces in active commercial use, etc.*—Continued.

REFLECTED-HEAT FURNACES—Continued.

Make.	No.	User.	Alloy.	Capacity tons per heat per furnace.	Total capacity tons.	Total kw. rating.	Total kw.
Baldy	1	Dayton Engineering Laboratories Co., Dayton, Ohio.	Aluminum.....	$\frac{1}{2}$	$\frac{1}{2}$	105	105
	2	do.....	Brass and bronze	$\frac{1}{2}$	$\frac{1}{2}$	50	100
	1	Deening Co., Salem, Ohio.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	50	50
	3	Detroit Brass Works, Detroit, Mich.	Brass	$\frac{1}{2}$	2 $\frac{1}{2}$	105	315
	1	Drew Electric & Manufacturing Co., Cleveland, Ohio.	Brass and bronze	$\frac{3}{4}$	$\frac{3}{4}$	105	105
	1	Everette Motor Co., Milwaukee, Wis.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	75	75
	1	Flood City Manufacturing Co., Johnstown, Pa.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	75	75
	1	Hays Manufacturing Co., Erie, Pa.	Brass	$\frac{3}{4}$	$\frac{3}{4}$	105	105
	1	Kayline Co., Cleveland, Ohio.	Brass and bronze	$\frac{1}{2}$	$\frac{1}{2}$	50	50
	1	Oscar Krenz Copper & Brass Works, San Francisco, Calif.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	75	75
	1	Kennedy Valve Co., Elmira, N. Y.	do.....	$\frac{3}{4}$	$\frac{3}{4}$	105	105
	1	Landers, Frary & Clark, New Britain, Conn.	Aluminum.....	1 $\frac{1}{2}$	1 $\frac{1}{2}$	50	50
	2	Lumen Bearing Co., Buffalo, N. Y.	Brass and bronze	$\frac{3}{4}$	1 $\frac{1}{2}$	105	210
	1	do.....	Lumen metal...	$\frac{1}{2}$	$\frac{1}{2}$	105	105
	1	Miller Pasteurizing Machine Co., Canton, Ohio.	Brass and bronze	$\frac{1}{2}$	$\frac{1}{2}$	50	50
	4	Michigan Smelting & Refining Co., Detroit, Mich.	Brass	$\frac{3}{4}$	3	105	420
	1	A. Y. McDonald, Co., Dubuque, Iowa.	Brass and bronze	$\frac{3}{4}$	$\frac{3}{4}$	105	105
	1	McKenzie Brass Works, Pittsburgh, Pa.	do.....	$\frac{3}{4}$	$\frac{3}{4}$	105	105
	1	do.....	do.....	$\frac{1}{2}$	$\frac{1}{2}$	50	50
	1	Metrie Metals Co., Erie, Pa.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	75	75
	3	McRae-Roberts Co., Detroit, Mich.	do.....	$\frac{1}{2}$	2 $\frac{1}{2}$	105	315
	1	W. A. Mills, Port Chester, N. Y.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	75	75
	3	H. Mueller Manufacturing Co., Decatur, Ill.	do.....	$\frac{3}{4}$	2 $\frac{1}{2}$	105	315
	2	Nolte Brass Co., Springfield, Ohio.	do.....	$\frac{3}{4}$	2 $\frac{1}{2}$	105	315
	1	Ore Metals Co., Los Angeles, Calif.	do.....	$\frac{3}{4}$	$\frac{3}{4}$	105	105
	1	H. Orne & Sons, St. Paul, Minn.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	75	75
	1	Perberthy Injector Co., Detroit, Mich.	do.....	$\frac{3}{4}$	$\frac{3}{4}$	105	105
	1	Pittsburgh Valve & Fixture Co., Barbours, Ohio.	do.....	$\frac{3}{4}$	$\frac{3}{4}$	105	105
	1	Chas. D. Reeve Co., Grand Rapids, Mich.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	50	50
	1	Regent Brass Works, Marysville, Ohio.	do.....	$\frac{3}{4}$	$\frac{3}{4}$	105	105
	1	Rundle Manufacturing Co., Milwaukee, Wis.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	75	75
	1	Springfield Brass Works, Springfield, Ohio.	do.....	$\frac{3}{4}$	$\frac{3}{4}$	105	105
	2	Standard Sanitary Co., Louisville, Ky.	do.....	$\frac{3}{4}$	3 $\frac{1}{2}$	105	525
	1	Sentry Gyroscope Co., New York, N. Y.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	75	75
	1	S. H. Thomson Manufacturing Co., Dayton, Ohio.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	50	50
	2	Union Brass & Metal Manufacturing Co., St. Paul, Minn.	do.....	$\frac{3}{4}$	1 $\frac{1}{2}$	105	210
	1	Union Screw Plate Co., Fitchburg, Mass.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	75	75
	1	U. S. Copper Products Co., Cleveland, Ohio.	Brass	$\frac{3}{4}$	$\frac{3}{4}$	105	^a 105
	1	U. S. Navy Yard, Washington, D. C.	Brass and bronze	$\frac{3}{4}$	$\frac{3}{4}$	105	^a 105
	1	U. S. Arms, Rif., and Mining Co., Boston, Mass.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	75	75

^a Being installed.^b New fitting.

TABLE 1.—*Electric furnaces in active commercial use, etc.*—Continued.

REFLECTED-HEAT FURNACES—Continued.

Make.	No.	User.	Alloy.	Capacity tons per heat per furnace.	Total capacity tons.	Total kw. rating.	Total kw.
Baily.....	1	Utica Valve & Fixture Co., Utica, N. Y.	Brass and bronze	$\frac{1}{2}$	$\frac{1}{2}$	105	105
	1	Westinghouse Electric Manufacturing Co., East Pittsburgh, Pa.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	50	50
	2	West Virginia Metal Products Co., Fairmont, W. Va.	do.....	$\frac{1}{2}$	1 $\frac{1}{2}$	105	" 210
	1	White & Bros., Philadelphia, Pa.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	105	105
	1	J. B. Wise, Inc., Watertown, N. Y.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	75	75
	1	Wolverine Brass Works, Grand Rapids, Mich.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	50	50
Total ^a	83	Number of users, 57.....			51.7		7,455
General Electric.	1	General Electric Co., Schenectady, N. Y.	Aluminum.....	$\frac{1}{2}$	$\frac{1}{2}$	75	75
	1	do.....	do.....	$\frac{1}{2}$	$\frac{1}{2}$	150	150
	1	do.....	Brass and bronze	$\frac{1}{2}$	$\frac{1}{2}$	250	250
	1	McNab & Harlin Manufacturing Co., Paterson, N. J.	"Aterite".....	$\frac{1}{2}$	$\frac{1}{2}$	300	300
	1	do.....	do.....	1 $\frac{1}{2}$	1 $\frac{1}{2}$	400	400
	1	U. S. Copper Products Co., Cleveland, Ohio.	Brass and copper.	1 $\frac{1}{2}$	1 $\frac{1}{2}$	400	400
	1	Ohio Brass Co., Mansfield, Ohio.	Brass and bronze	1 $\frac{1}{2}$	1 $\frac{1}{2}$	400	400
	1	U. S. Navy Yard, Washington, D. C.	do.....	1 $\frac{1}{2}$	1 $\frac{1}{2}$	400	400
Total.....	8	Number of users, 5.....			5.75		2,375
Remmert re-verberatory.	1	Chicago Faucet Co., Chicago, Ill.		$\frac{1}{2}$	$\frac{1}{2}$	75	75
Total for type..	92	Number of users, 62.....			57		9,730

VERTICAL-RING INDUCTION FURNACES—SINGLE PHASE.

Ajax-Wyatt....	3	Ajax Metal Co., Philadelphia, Pa.	Yellow brass....	$\frac{1}{2}$	$\frac{1}{2}$	30	90
	1	do.....	do.....	$\frac{1}{2}$	$\frac{1}{2}$	60	60
	32	American Brass Co., Waterbury, Conn.	do.....	$\frac{1}{2}$	16	60	19.0
	24	American Brass Co., Kenosha, Wis.	do.....	$\frac{1}{2}$	12	60	1.440
	24	American Brass Co., Torrington, Conn.	do.....	$\frac{1}{2}$	12	60	1.440
	1	American Hardware Co., New Britain, Conn.	Yellow and red brass.	$\frac{1}{2}$	$\frac{1}{2}$	30	30
	6	Baltimore Tube Co., Baltimore, Md.	Yellow brass....	$\frac{1}{2}$	3	60	360
	17	Bridgeport Brass Co., Bridgeport, Conn. ^a	do.....	$\frac{1}{2}$	5 $\frac{1}{2}$	70	850
	6	do.....	do.....	$\frac{1}{2}$	4 $\frac{1}{2}$	80	480
	1	Buick Motor Car Co., Flint, Mich.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	60	60
	26	Chase Rolling Mill Co., Waterbury, Conn.	do.....	$\frac{1}{2}$	13	60	1.440
	1	Crane Co., Chicago, Ill.	Red brass.....	$\frac{1}{2}$	$\frac{1}{2}$	60	60
	1	Erie-Buffalo Tube Co., Erie, Pa.	Yellow brass....	$\frac{1}{2}$	$\frac{1}{2}$	60	60
	1	General Electric Co., Schenectady, N. Y.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	60	60
	1	Haines, Jones & Cadbury, Philadelphia, Pa.	Red brass.....	$\frac{1}{2}$	$\frac{1}{2}$	60	60
	6	National Conduit & Cable Co., Hastings, N. Y.	Yellow brass....	$\frac{1}{2}$	3	60	360

^a Nose tilting.

^b Two 105 kw. furnaces are also used by Metal & Thermit Co., Chicago, for tin recovery. Other Baily furnaces are installed in Canada and Mexico as follows: Canada, Empire Brass Works, one 105-kw.; Monarch Metal Co., one 50-kw.; Dominion Steel Products Co., one 50-kw.; Mexico, G. Amsinck Corp., two 105-kw.

^c This firm originally used mostly the 30-kw. size, but has changed to a smaller number of higher-powered furnaces.

TABLE 1.—*Electric furnaces in active commercial use, etc.*—Continued.

VERTICAL RING INDUCTION FURNACES—SINGLE PHASE—Continued.

Mfg.	No.	User.	Alloy.	Capacity tons per heat per furnace.	Total capacity tons.	Total kw. rating.	Total kw.
Ajax-Wyatt.	1	Raritan Copper Works, Raritan, N. J.	Yellow brass....	$\frac{1}{2}$	$\frac{1}{2}$	60	60
	1	Parish Pool Co., Cleveland, Ohio.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	60	60
	3	Rome Brass & Copper Co., Rome, N. Y.	do.....	$\frac{1}{2}$	1 $\frac{1}{2}$	60	180
	12	Seoville Manufacturing Co., Waterbury, Conn.	do.....	$\frac{1}{2}$	6	60	720
	1	Speakman Co., Wilmington, Del.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	60	60
	1	Specialty Brass Co., Kenosha, Wis.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	60	60
	1	Stamford Rolling Mills Co., Stamford, Conn.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	60	60
	1	Standard Sanitary Manufacturing Co., Louisville, Ky.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	75	75
	2	Standard Underground Cable Co., Perth Amboy, N. J.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	60	120
	6	West Virginia Metal Products Co., Fairmont, W. Va.	do.....	$\frac{1}{2}$	3	60	360
	1	Western Cartridge Co., W. Alton, Ill.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	60	60
	1	U. S. Navy Yard, Washington, D. C.	do.....	$\frac{1}{2}$	$\frac{1}{2}$	60	60
Total	476	Number of users, 24.....			84.3		14,085

HORIZONTAL-RING INDUCTION FURNACES—SINGLE PHASE.

General Electric.	1	Hoskins Manufacturing Co., Detroit, Mich.	Nickel-chromium	$\frac{1}{8}$	$\frac{1}{8}$	100	100
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CONTACT-RESISTANCE FURNACES—THREE PHASE.

Bennett.	1	Seoville Manufacturing Co., Waterbury, Conn.	Brass and copper.	5	5	500	500
	6	do.....	do.....	1	6	150	900
Total	7	Number of users, 1.....			11		1,400

HIGH-FREQUENCY EDDY-CURRENT FURNACES.

Ajax-Wyatt.	1	Baker & Co., Newark, N. J....	Platinum.....			18	$\approx$ 18
	1	H. A. Wilson Co., Newark, N. J.	do.....			20	$\approx$ 20
	1	D. Belais, New York City.....	White gold.....			20	$\approx$ 20
	1	Goldsmith Bros. Smelting & Refining Co., Chicago, Ill.	Precious metals.....			20	$\approx$ 20
	2	U. S. Mint, Philadelphia, Pa.	Silver and gold.....			8	$\approx$ 6
	2	do.....	do.....			16	$\approx$ 32
	1	Handy & Harman, Bridgeport, Conn.	Silver.....	$\frac{1}{4}$	$\frac{1}{4}$	60	$\approx$ 60
Total	9	Number of users, 6.....			$\frac{1}{4}$		186

* Single phase, crucible lift-out.

* Two phase, crucible lift-out.

* Three phase, none tilting.

** The number of Bennett furnaces in use by the Seoville Mfg. Co. has been increased by about a dozen since this table was prepared.

TABLE 1.—*Electric furnaces in active commercial use, etc.*—Continued.

OTHER CRUCIBLE LIFT-OUT FURNACES.

Make.	No.	User.	Alloy.	Capacity tons per heat per furnace.	Total capacity tons.	Total kw. rating.	Total kw.
Baily.....	1	W. A. Rogers, Ltd., Niagara Falls, N. Y.	Silver.....	$\frac{1}{30}$	$\frac{1}{30}$	4	aa 40
	1	U. S. Smelt. Ref. & Mining Co., Boston, Mass.					
Marsh.....	2	bb Hoskins Manufacturing Co., Detroit, Mich.	Nickel-chromium	$\frac{1}{20}$	$\frac{1}{10}$	50	cc 100
Total.....	4	Number of users, 3.....			$\frac{2}{15}$		140

SUMMARY.

Make.	Number of furnaces.	Total capacity per heat tons.	Total kilowatts.
Ajax-Wyatt.....	176	84.3	14,085
Detroit rocking.....	60	54.4	16,325
Baily.....	83	51.7	7,455
Booth.....	40±	13.2	5,345
Other furnaces.....	54	30.1	7,661
Total.....	413	233.7	50,861

aa Single phase, two crucibles.

bb These furnaces are used less than formerly on account of the installation of larger furnaces of other types.

cc Single phase, one or two crucibles per furnace.

Various other types are still under experimental development.

After the year 1916 began the period of commercial introduction and development of electric brass furnaces. The status of the industry, which was still in its infancy, was thus given in a review ⁷ of electrometallurgy in 1919:

In the nonferrous metal industries, 1919 was characterized by the rapid introduction of electric melting furnaces in place of melting in crucibles or open-combustion furnaces. The electric furnace had a great opportunity and it was grasped. Fifty or more electric furnaces were erected in a single brass-producing city, and all the other brass makers in the country are either looking on with interest or have determined to follow suit. America is leading the world in this development, and the brass and other related industries of other countries can not do otherwise than imitate our methods and follow our lead.

Richards ⁸ says: "It will be but a short time before all the brass in this country will be melted by electric furnaces."

The Metal Industry ⁹ said, in May, 1919: "We can now repeat with more emphasis what we said in an editorial last October: 'The electric furnace has arrived.'"

The importance of the development of electric brass furnaces will be made clearer by considering the savings possible by their use.

⁷ Electrometallurgy in 1919: Chem. and Met. Eng., vol. 22, 1920, p. 2.

⁸ Richards, J. W., Electrochemistry: Elect. Rev., vol. 74, 1919, p. 992; compare also Parsons, F. W., Everybody's business, electric heat to-morrow: Sat. Even. Post., vol. 192, 1920, Jan. 24, pp. 39, 73.

⁹ Electric-furnace progress: Metal Ind., vol. 17, 1919, p. 230; see also vol. 18, 1920, p. 65; see also Cone, E. F., Electric melting in nonferrous industry: Iron Age, vol. 105, 1920, p. 655.

MONETARY SAVING POSSIBLE BY ADOPTION OF ELECTRIC BRASS MELTING.

The saving due to the adoption of electric brass melting will, of course, vary with the conditions and the location of the plant, but suppose that electric melting had progressed so far that all melting had been done electrically during the war. In 1917, according to the War Industries Board,¹⁰ 1,072,508,000 pounds of brass and bronze were made, mostly yellow brass. To produce this, at least a third as much more scrap and crop ends had to be melted. The total melt may be estimated at 1,430,000,000 pounds.

Metal losses were high during the rush of war production, and it seems very probable that the melting loss with electric furnaces would have been 2 per cent less than with crucibles, so that the saving would have been about 28,500,000 pounds of metal. This lost metal was mainly zinc, having an average price, for rolling-mill spelter, of 11 cents,¹¹ but partly copper, with an average of 31 cents.¹¹ On the assumption that this 2 per cent loss was $1\frac{1}{2}$ per cent zinc and $\frac{1}{2}$ per cent copper, the average value of the lost metal was then 16 cents and the possible saving in metal alone was \$4,500,000. As crucibles and labor were both higher than ever before, an equal amount, at least, should be allowed for savings through not using crucibles and approximately \$1,000,000 through savings in labor, or a total of \$10,000,000.

The domestic consumption of copper rose from 1,316,463,754 pounds in 1917 to 1,800,000,000 pounds, or thereabout, in 1918, and the brass production doubtless increased in about the same proportion, or enough to offset the slightly lower prices of zinc, about 10 cents, and of copper, about 25 cents.¹² Crucibles and labor still remained high, so it is reasonable to figure that if all brass made in the country could have been melted electrically in 1917 and 1918 the war expenses of the country would have been reduced some \$20,000,000.

In 1919, when the domestic consumption of copper was 800,000,000 pounds, that of brass and bronze was, say, 600,000,000 pounds, and the capacity¹³ of the copper-using plants was over twice that figure, including that from secondary metals. The total melt to produce that amount of brass and bronze may be assumed as 800,000,000 pounds. With the average 1919 price of copper as $19\frac{1}{2}$ and that of zinc as 8 cents per pound, and the metal saving to be made by electric melt-

¹⁰ Mitchell, W. C., Aldrich, H. R., and Schmuckler, J. History of prices during the war: War Industries Board publication, 1919; *Foundry*, vol. 47, 1919, p. 862; *Metal Industry* (London), vol. 15, 1919, p. 455.

¹¹ Anonymous, Waterbury average; *Metal Ind.*, vol. 16, 1918, p. 582.

¹² Anonymous, Waterbury average; *Metal Ind.*, vol. 17, 1919, p. 108; vol. 18, 1920, p. 116.

¹³ See Bregman, A., The distribution of copper; *Metal Ind.*, vol. 18, 1920, p. 220.

ing taken as $1\frac{1}{2}$ per cent, or about 6,000 tons (say 4,000 tons of zinc and 2,000 tons of copper), the preventable loss of metal figures out as more than a third of a million dollars. This figure is based only on the net saving of metal and does not include the money saved by the avoidance of the need of recovering from the slag and ashes much metal that has thus to be recovered in fuel-fired practice. The saving due to reduction of gross loss is not far from that due to reduction of net loss. Add to these savings those due to savings in crucibles, fuel, and labor and it appears that, roughly speaking, under peacetime conditions the country will save annually two or three million dollars, perhaps more, by going completely over to electric brass melting. Under the conditions of low production and low metal prices prevailing in the latter part of 1920 and during 1921 the saving would be less, but over a term of years it would average at least the figure given. Whether any particular plant is so situated that it can save part of that sum for itself by using electric furnaces or whether it is one of the small minority so situated that electric melting would cost more than clinging to the older methods is a question to be answered only by careful consideration of the location of each plant and the conditions there. It is hoped that this report may aid in answering the question.

SAVINGS DUE TO MORE HEALTHFUL CONDITIONS.

Besides the readily recognizable saving in dollars and cents due to electric melting there is another saving less easily calculated, but no less real. The electric furnace is cooler, cleaner, and gives less zinc fume than older methods of melting. One rolling mill that has changed completely to electric melting has had no case of "brass shakes" since the fuel-fired furnaces were abandoned, and the number of severe burns has been greatly reduced. On account of the cooler and cleaner working conditions, the elimination of much hard manual labor, and the avoidance of zinc fume the electric furnace is no small factor in improving the comfort, health, and safety of the workmen. It was this point, no less than the possibilities of the electric brass furnace as a factor in the conservation of our natural resources, that caused the Bureau of Mines to undertake its investigation of melting brass in electric furnaces.

WORK OF THE BUREAU OF MINES.

The actual work of the Bureau of Mines on electric brass melting began in September, 1912, at a field office established at Morse Hall, Cornell University, Ithaca, N. Y., where, by the courtesy of the uni-

versity, the excellent facilities of the electric-furnace laboratory and other laboratories of the department of chemistry were, through a cooperative agreement, made available for the work of the bureau.

The work has been in three phases: (1) Collection of data, for comparison, on the performance of fuel-fired brass furnaces, which have been published as Bulletin 73¹⁴; (2) experimental work to show whether zinc losses could be reduced by electric melting, without regard to the question of whether or not the type of furnace used was likely to be commercially useful, which showed that the losses could be materially reduced, and finally (3) attempts to find out, through laboratory tests, inspection of commercial furnaces, attendance at commercial tests, and collection of data, what different types of electric furnaces have done or may be expected to do under various conditions.

The preliminary work on zinc losses was done mainly in crucible furnaces—first, because they were easier to handle on an experimental basis for the purpose in view, and, second, because it seemed desirable to start with an electrically heated furnace of a general type with which, in fuel-fired form, all foundrymen are familiar. Some of the preliminary work was reported¹⁵ at the 1914 meeting of the American Institute of Metals. The early work was confined mainly to brasses high in zinc, because the possibilities of metal saving were greatest for those alloys and because, at the prices then prevailing for coke, coal, fuel oil, metals, and crucibles, it was clear that the cost of electric power being higher than that of fuel made necessary the development of electric melting to a high degree of perfection before it could compete, on a cost basis, with fuel where the alloy melted was low in zinc and little saving of metal could be expected.

The outbreak of the European war, with the subsequent rise in cost of metals, fuel, and crucibles—the latter accompanied by a marked decrease in quality—altered conditions materially and gave experimenters greater incentive to carry on and complete their work. As the cost of crucibles had risen to unprecedented heights, the elimination of crucibles made possible so great a saving that electric melting in noncrucible furnaces became applicable to red brass and bronze, irrespective of the metal savings.

At the same time users of fuel-fired furnaces made every effort to limit the use of crucibles to alloys that absolutely required them. Crucibles were still generally used in melting yellow brass, but open-

¹⁴ Gilbert, H. W. Brass furnace practice in the United States; Bull. 73, Bureau of Mines, 1914, 298 pp.

¹⁵ Gilbert, H. W., and Lebr. J. M., Melting losses in electric brass furnaces. This paper was preprinted and read, but as the data were to be included in a bulletin of the Bureau of Mines it was not printed in the transactions of the Institute. See Trans. Am. Inst. Metals, vol. 5, 1914, p. 11; Met. and Chem. Eng., vol. 12, 1914, p. 647.

flame oil furnaces very largely displaced crucibles for melting red brass and bronze, the determining factor being, of course, the zinc content of the alloy.

When the United States entered the war these conditions became even more altered from those prevailing in 1912 to 1914. Economy in materials, labor, and money outlay was not only commercially desirable, but became a patriotic duty. As a result during the war the development of electric brass melting received great impetus. The bureau's interest in the work increased as the problem from being mainly one of conserving zinc and promoting health and safety in foundries came to include the imperative need of producing munitions and essential war materials more cheaply and rapidly.

The bureau's work included the laboratory development and semi-commercial testing of the rocking type of furnace, which has been brought into commercial use by the Detroit Electric Furnace Co. that is licensed under Bureau of Mines patents to manufacture and sell it. The work on the rocking furnace has been related fully,¹⁶ and reference to that furnace in this report will be confined mainly to the performance of the commercial installation of this type made since the bureau's experiments were finished.

The Bureau of Mines, besides doing experimental work, has been privileged, through the cordial cooperation of inventors and makers of electric furnaces, of their users, and of central stations, to collect much data—by attendance at tests, by inspection of furnaces in commercial operation, as well as by correspondence—on the operation of most of the various types of electric brass furnaces now in use, on many of the discarded types, and on those still being developed. Some data already have been reported briefly.¹⁷

ACKNOWLEDGMENTS.

Grateful acknowledgment is made for his active interest and support to Dr. C. L. Parsons, formerly chief chemist of the Bureau of Mines to whose initiative the bureau's work on this problem is due, and under whose direction it was mainly carried out; and to Dr. J. M. Lohr and Mr. A. E. Rhoads, formerly of the bureau, for efficient aid in experimental work.

Thanks are due Cornell University for the use, under cooperative agreement, of its electric furnace laboratory and other equipment.

¹⁶ Gillett, H. W., and Rhoads, A. E., Melting brass in a rocking electric furnace: Bull. 171, Bureau of Mines, 1918, 131 pp.; A rocking electric brass furnace: Jour. Ind. Eng. Chem., vol. 10, 1918, p. 459; Met. and Chem. Eng., vol. 18, 1918, p. 583.

¹⁷ Gillett, H. W., Utilization of electric brass furnaces: Jour. Ind. Eng. Chem., vol. 11, 1919, p. 664; Chem. and Met. Eng., vol. 21, 1919, pp. 6, 116; Electrical melting of alloys (serial): Foundry, vol. 48, 1920, pp. 177, 229, 275, 319, 362, 400, 445, 486, 531, 571, 612, 656, 693; Electric furnaces for nonferrous alloys: Trans. Am. Electrochem. Soc., vol. 39, 1921, p. 277.

utilized in the experimental work, as well as to Professors W. D. Bancroft and T. R. Briggs, in charge of electrochemical work at Cornell University, for many courtesies.

So many makers and users of electric brass furnaces have cooperated by furnishing data and information that a complete acknowledgment would list practically everyone interested in the problem. The bureau's thanks are due to all these firms and individuals, and particularly to those who permitted representatives of the bureau to watch their furnaces in operation. Special mention should be made of the constructive cooperation of the Detroit Edison Co., through Mr. E. L. Crosby, and of the Commonwealth Edison Co., Chicago, through Mr. H. M. St. John.

DIFFERENT TYPES OF ELECTRIC BRASS FURNACES.

Not less than 80 different types or different makes of the same type of furnaces have been used, tried, or suggested for melting copper, brass or bronze, aluminum, or nickel alloys. These are listed in Table 2 in the order in which they are described in the text. Mention is made in the text of types as well suited to melting these materials, as are many of those in the list, many of which are purely "paper furnaces" that probably never existed except in patent specifications. If the patent specifications, however, definitely state that the furnace is designed for melting brass instead of merely mentioning the melting of metals in general, it has been included. If one furnace made by the same person or firm differs from another only in size and not in type or design, but one entry is made. On the other hand, the same type or design as made by different persons or firms is given a separate entry for each make. If it were possible to include all the types of furnaces on which no information is available and that have been tried out and abandoned by various workers, the list would be increased materially—probably to at least a hundred.

TABLE 2.—*Electric furnaces designed or tested for melting nonferrous metals.*

CRUCIBLE FURNACES.

No.	Name of designer or builder.	Used or tested by or at—	Type.	Distinguishing features.	Tests of use on nonferrous alloys.		
					Has had laboratory test.	Has had foundry test.	Present commercial use in United States, Jan. 1, 1922.
1	Fitzgerald.....	Titanium Alloys Manufacturing Co.	Crucible lift-out.	Granular resistor.	Yes.....	No.....	None.
2	Baily.....	W. A. Rogers (Ltd.).	Crucible lift-out, 2 pots.	do.....	.....	.....	One furnace melting silver.
3	do.....	Detroit Copper & Brass Rolling Mills.	Crucible lift-out, 8 pots.	do.....	.....	Yes.....	None.
4	Snyder.....	Commonwealth Edison Co.	Crucible lift-out.	Solid molded resistor.	.....	Yes.....	None.
5	Greenwood & Hutton.	English test.....	do.....	Solid grid resistor.	Yes.....	No.....	None.
6	Hoskins (Marsh).	Commonwealth Edison Co. and Bureau of Mines.	do.....	Carbon-plate resistor.	Yes, 16 sizes and modifications.	Yes.....	One or two furnaces melting nickel-chromium alloys.
7	Bureau of Mines.	Bureau of Mines.	Crucible lift-out, 3 pots.	Carbon-plate resistor between pots.	Yes.....	No.....	None.
8	Cadwell.....	.....	Crucible lift-out, 2 pots.	Granular resistor below arcs at side of pots.	.....	.....	None.
9	Rennerfelt reverberatory crucible.	.....	Crucible lift-out, several pots.	Arc resistance.	.....	.....	None.
10	General Electric Co.	General Electric Co.	Crucible tilting.	do.....	Yes.....	?.....	None.
11	Stansfield.....	.....	do.....	Granular resistor surrounding crucible.	?.....	.....	None.
12	Baily.....	.....	do.....	do.....	Yes.....	.....	None.
13	Bureau of Mines.	Bureau of Mines.	do.....	do.....	Yes.....	.....	None.
14	National Carbon Co.	.....	do.....	do.....	.....	.....	None.
15	General Electric Co.	.....	do.....	do.....	.....	.....	None.
16	Baily.....	Detroit Copper & Brass Rolling Mills.	do.....	Granular resistor below crucible.	.....	Yes.....	None.
17	Weintraub.....	General Electric Co.	do.....	Solid silicon-grid resistor.	.....	Yes.....	None.
18	Helberger.....	National Cash Register Co.	do.....	Solid resistor.	.....	Yes.....	None.
19	Electro-Metals Co. (Ltd.).	English test.....	do.....	do.....	Yes.....	No.....	None.
20	Morgan.....	do.....	do.....	do.....	?.....	?.....	Advertised for sale, but probably not used.
21	Conley.....	Electrical Testing Laboratory.	do.....	do.....	Yes.....	No.....	None.

TABLE 2.—*Electric furnaces designed or tested for melting nonferrous metal—*
Continued.

HEARTH FURNACES.

No.	Name of designer or builder.	Used or tested by or at—	Type.	Distinguishing features.	Tests of use on nonferrous alloys.		
					Has had laboratory test.	Has had foundry test.	Present commercial use in United States, Jan. 1, 1922.
22	Rockwell.....		Resistor below hearth.		Yes.....	No.....	None.
23	Bristol.....		Carbon-rod resistor.	Steam.....	?.....	No.....	None.
24	Clingman.....		do.....		?.....	?.....	None.
25	Johnson.....		Lattice resistor.	Pump for stirring.	No.....	No.....	None.
26	Fitzgerald-Thomson.		Resistor layer of rods.		Yes.....	No.....	None.
27	do.....		Self-supporting resistor.		Yes.....	No.....	None.
28	Thomson.....		Zigzag resistor.	Gyrating.....	?.....	?.....	None.
29	do.....		Tubular zigzag resistor.	Rotating.....	?.....	?.....	None.
30	Bensel.....	German test..	Carbon-rod resistor.	Rocking...	Yes.....	No.....	None.
31	Harvey.....		Resistor.	Rotating.....	?.....	No.....	None.
32	Haskins.....	Bureau of Mines.	Carbon-plate resistor overhead.		Yes.....	No.....	None.
33	Thornton.....		Carborundum resistor.		?.....	No.....	None.
34	Bureau of Mines.	Bureau of Mines.	Carborundum resistor between two hearths.		Yes.....	No.....	None.
35	Weindenthal.....		Carborundum resistors at sides.		?.....	No.....	None.
36	Erichsen.....		Carborundum resistors overhead.		?.....	No.....	None.
37	Dirzuweit.....	Baltimore Tube Co.	Granular resistor in troughs.			Yes.....	None.
38	Baily.....	Many users.	Granular resistor in circular trough.			Yes.....	Wide use, 82 furnaces.
39	do.....	Several trials.	Granular resistor in straight troughs at sides, large tapping furnace.		?.....	Yes, on aluminum and zinc.	None. Successfully used in annealing furnaces.
40	do.....	do.....	Granular resistor in straight trough over hearth.		?.....	Yes.....	None.
41	General Electric.	Several users.	Arcs and resistance, rectangular.		Yes.....	Yes.....	9 furnaces of both types.
42	do.....	General Electric Co.	Arcs and resistance, round.		Yes.....	Yes.....	
43	Remmertfelt resortatory.	Chicago Fan and Co.	Arcs and resistance.	Heat source between 2 hearths.	Yes.....	Yes.....	One.
44	Harcourt type.	Several users.	Direct arc.		Yes.....	Yes.....	2 on nickel alloys, none on brass or bronze.

TABLE 2.—*Electric furnaces designed or tested for melting nonferrous metal—*
Continued.

HEARTH FURNACES—Continued.

No.	Name of designer or builder.	Used or tested by or at—	Type.	Distinguishing features.	Tests of use on nonferrous alloys.		
					Has had laboratory test.	Has had foundry test.	Present commercial use in United States, Jan. 1, 1922.
45	Snyder.....	Several users..	Direct arc.....		Yes.....	Yes.....	6 on nickel or cobalt alloys, 2 on leaded bronze.
46	Greaves-Etchells.	Hoskins Manufacturing Co.	do.....			Yes.....	1 on nickel alloys.
47	Bureau of Mines.	Bureau of Mines.	do.....		Yes.....	No.....	None.
48	Wile.....	Several trials..	Slag resistance.	Glass slag...	Yes.....	Yes.....	None.
49	Bennett.....	Scovill Manufacturing Co.	Contact resistance.	Low voltage.	Yes.....	Yes.....	7 large furnaces.
50	De Nolly-Grammont.	French test...	Direct arc.....	Large electrodes.		Yes.....	None in United States.
51	Von Schlegell-Fletcher.		Direct arc, then indirect arc.		?	No.....	None.
52	Moldenke.....		Indirect arc.	Charge preheated by fuel.	No.....	No.....	None.
53	Weeks.....	Weeks and Hansen.	do.....		Yes, on copper only.	No.....	None.
54	Shipton.....		do.....	Shelf over arc.	No.....	No.....	None.
55	Indianapolis...	(?)	do.....		Yes.....	(?)	None.
56	Stassano type.	General Electric Co.	do.....		Yes.....	(?)	None.
57	Stassano-Petionot.	(?)	do.....		(?)	(?)	None.
58	Bureau of Mines.	Bureau of Mines.	do.....		Yes.....	No.....	None.
59	Rennerfelt.....	Several users..	do.....		Yes.....	Yes.....	8 furnaces.
60	Re-pel-arc (von Schlegell).	do.....	do.....	Repelling arc.	Yes.....	Yes.....	6 furnaces.
61	Bureau of Mines.	Bureau of Mines and Michigan Smelting and Refining Co.	do.....	Rocking...	Yes.....	Yes.....	See No. 62.
62	Detroit.....	Many users..	do.....	do.....		Yes.....	Wide use 60 furnaces, mostly large.
63	Universal.....	Jos. Brenner & Co.	do.....	do.....		Yes.....	None.
64	Tooth.....	Many users..	do.....	Rotating...		Yes.....	Considerable use, 40 furnaces, mostly small.
65	American.....		do.....	Revolving...	(?)	No.....	None.
66	Moore.....	(?)	do.....	do.....	(?)	None.....	None.
67	Reardon.....		do.....	Rocking...		No.....	None.
68	Volta.....	Titanium Bronze Co.	do.....	Gyrating...	Yes.....	Yes.....	None.
69	Colby-Kjellin type.	Several trials..	Induction...	Horizontal ring.	Yes.....	No.....	None except 1 on nickel alloys.
70	Spencer.....	Pierce Arrow Motor Car Co.	do.....	do.....	Yes.....	No.....	None.
71	Kjellin.....	English test...	do.....	do.....	Yes.....	No.....	None.

TABLE 2.—*Electric furnaces designed or tested for melting nonferrous metal—Continued.*

HEARTH FURNACES—Continued.

No.	Name of designer or builder.	Used or tested by or at—	Type.	Distinguishing features.	Tests of use on nonferrous alloys.		
					Has had laboratory test.	Has had foundry test.	Present commercial use in United States, Jan. 1, 1922.
72	Roechling-Rodenhauser.	Baltimore Copper Smelting and Rolling Co.	Induction...	Horizontal ring.	.....	Yes.....	None.
73	Harden.....	.....	do.....	Horizontal ring with modifications.	(?)	No.....	None.
74	Gehrkeus.....	.....	do.....	do.....	(?)	(?)	None.
75	Greene.....	.....	do.....	do.....	(?)	No.....	None.
76	Hosard.....	.....	do.....	do.....	(?)	No.....	None.
77	Hering.....	Several trials..	Pinch effect.	Resistor tubes.	Yes.....	Yes.....	None.
78	Foley.....	Bristol Brass Co.	Induction...	Vertical ring.	Yes.....	Yes.....	None.
79	Brophy.....	.....	do.....	Vertical ring with modifications.	(?)	No.....	None.
80	Ajax-Wyatt...	Many users...	do.....	Vertical ring	Yes.....	Yes.....	98 furnaces
81	Clark.....	.....	do.....	Vertical ring with modifications.	(?)	No.....	None.
82	Ajax-Northrup	Handy and Harmon, etc.	Eddy current, tilting.	High frequency current.	Yes.....	Yes.....	9 on silver, gold, and platinum.
83	General Electric.	General Electric Co.	Nickel-chromium resistor.	Special for aluminum.	Yes.....	.....	None.

Note. Another electrical brass furnace, made by Wm. Swindell & Bros., Pittsburgh, Pa., was advertised as ready for commercial use late in 1921, but no description is yet available.

The same idea held by different people or different ideas held by the same person have produced 80 or more forms of electric brass furnaces, of which at least 50 have been actually tested in melting copper, brass, or bronze. Some of these never completed the first heat, whereas others in commercial use by scores of firms have melted huge tonnages of metal.

The surviving types of furnaces, therefore, represent the fruit of a vast amount of thought, of experiment, and of commercial elimination of the unfit. This process of development and elimination will continue, and the perfect electric brass furnace, though it may be evolved in the future, is still nonexistent. Crude as all types may seem in the light of future developments, there are several types that are of present commercial value and are ready for foundry use.

OBJECT OF THIS REPORT.

The object of this report is twofold: First, to collect all necessary and pertinent information available on what commercial furnaces are

doing and can do, in order that the prospective user may have data for forming a decision as to whether to install any electric furnace and for selecting a type of furnace fitted to his requirements; second, to show, by description and by data on experimental tests, the gradual evolution of the present commercial types, and by including information on failures as well as successes to save future workers in this field the labor of following the steps of previous workers.

Another object is to point out some of the fundamental principles in the design, construction, and operation of electric brass furnaces. Part of the information in this report has been published before, but it was written chiefly from one viewpoint or in connection with some particular furnace. This report considers the subject broadly.

THEORETICAL ADVANTAGES OF ELECTRIC MELTING.

The study of the various furnaces will be facilitated by first considering the theoretical advantages of electric brass furnaces. These advantages are as follows:

1. Melting may take place in a neutral or reducing atmosphere, thus minimizing loss of metal by oxidation and improving the quality of the product through freedom from oxides.

2. Metal of crucible quality may be obtained without the use of crucibles.

3. Melting may take place in a tightly closed chamber, or at least in one free from the constant passage of the products of combustion of fuel, and thus losses of volatile metals such as zinc and lead may be reduced. Contamination by sulphur from fuel is avoided.

4. In some types of electric furnaces the temperature may be more readily controlled than in fuel-fired furnaces.

5. In some types of furnaces the molten metal is thoroughly stirred, thus giving a uniform product, even with large heats.

6. There is no handling or storage of fuel, such as coke, coal, or oil, and no ashes have to be removed. The cost of power can be accurately predicted over longer periods than the cost of fuel.

7. Working conditions about the furnaces are less dangerous to health and safety of workmen, provided suitable types of furnaces are chosen.

8. The above advantages may be obtained in furnaces of larger capacity than can be used satisfactorily in the fuel-fired crucible types, with resulting greater uniformity of product, lower labor cost, and increased production.

There is no occult or mysterious effect on the metal from its having been "under the influence of electricity." Whatever improvement in quality results is largely due to the fact that electric heat is "clean" and permits the avoidance of oxidation, etc. If one could find a brick that would absorb enough heat to do the work, heat it, drop it into a crucible charged with brass, and cover the crucible,

thus melting the metal by the heat stored in the brick, he would melt the brass under about the same conditions as with an electrically heated crucible. The action of an electric furnace is no more mysterious than that of the hypothetical brick. The electric current is used merely as a means of producing heat, and no subtle alchemistic influence is exerted on the metal.

The general opinion of users of electric brass furnaces seems to be that the average product is no better and no worse than the metal from a well-operated fuel-fired crucible and that, owing to melting in larger units and to the use of furnaces that mix the charge thoroughly, the product is, in general, more uniform. On account of the uniformity of electrically melted metal the Bridgeport Brass Co. declares that electric furnaces make better condenser tubing and permit closer working to specification as to analysis. As the uniformity from perfect mixing in the electric furnaces used by this firm would naturally decrease the danger of electrolytic attack, the claim of superior quality seems justified, though it is probably a superior average quality rather than an improvement over the best crucible product. Claims are sometimes made¹⁸ that the physical properties of electrically melted cast brass are slightly superior to those of brass melted by fuel, but the advantage claimed is so slight that it might as readily be due to such factors as differences in pouring temperatures as to actually improved quality of the metal.

At any rate, it is not evident that anyone is relying enough on the added strength of electrically melted metal to have the courage to cut down the cross section and weight of castings made from it.

The basic electric steel furnace can take cheap, low-quality scrap and, by the use of refining slags, can make a high-grade product. Usually no analogous refining of nonferrous metals can be done in electric brass furnaces, though the ability of the electric furnace to handle borings and turnings with less metal loss than crucibles may sometimes permit the use of cheaper materials by allowing an increase in the proportion of borings used. There seems, however, to be a general impression that electric steel of a given analysis is better than even crucible steel of the same analysis, though this point is still open to discussion. A superiority similar to that alleged for electric steel may exist for electric brass, but its definite proof is even farther from being complete. In fact, there have been cases where electrically melted metal has not seemed to be as satisfactory as that from crucibles, though in other very similar circumstances it has been found to be just as good.

Various other alleged reasons for the superiority of electric brass furnaces have been brought up by furnace makers, such as the

¹⁸ Compare Collins, E. F., *Electric furnace for melting nonferrous metals*: Jour. Cleveland Eng. Soc., vol. 11, 1919, p. 293.

possibility of carrying the furnace to the mold and pouring from it direct, which might be practical in some cases, but is of extremely slight importance in any discussion of the general advantages of electric brass melting.

PRACTICAL ADVANTAGES OF ELECTRIC BRASS FURNACES.

The real reason for the rapidly growing use of electric brass furnaces is a highly practical one. Such furnaces properly chosen for the work in hand, in a large majority of cases, can produce metal of satisfactory quality at a lower total melting cost than fuel-fired furnaces. They save metal and labor, they increase production, they eliminate crucibles. The value of these factors overbalances the interest charge on the high first cost of the electric furnace and the higher cost, compared with fuel, under most conditions, of the electric current required.

Not every foundry is so situated that electric melting is cheaper than melting by fuel, and neither electric furnaces in general, nor, still less, any particular type or make of electric furnace, can be advocated as a panacea for all nonferrous melting problems. A careful consideration of plant conditions and of the performance of all types of electric furnaces operating under similar conditions, as far as such operation can be found, is essential before deciding to change from fuel-fired to electric furnaces.

When such a careful consideration of conditions is made, however, it is evident that, taking the brass industry as a whole, the economic conditions so strongly favor electric melting that it is probably only a matter of time, and not a very long time, before such melting will become standard practice for brass and bronze. Already the use of electric furnaces is growing at a more rapid rate in the brass industry than during the analogous period in the history of the steel industry, and the ratio of the tonnage of electric brass to the total tonnage is already much greater than that of electric steel to the total output of steel. There are almost, if not quite, as many electric furnaces installed for melting nonferrous alloys in the United States to-day as there are for electric steel.

DIFFERENCES BETWEEN BRASS MELTING AND STEEL MELTING.

Consideration of theoretical advantages and of the high state of perfection that the electric furnace has attained for melting steel might give the impression that the application of the electric steel furnace to the melting of nonferrous alloys is a simple matter, and that because of the lower melting points of brasses and bronzes their melting should be simpler than that of steel. If certain physical properties of molten steel and of molten brass be considered, however, it will be seen that steel and brass offer two distinct sets of conditions.

TYPES OF STEEL FURNACES.

According to Miller,^{18a} on January 1, 1917, out of 155 electric steel furnaces in the United States and out of 471 in the world the proportions of the different types were as follows:

Proportions of different types of electric steel furnaces in the United States and in the world.

	Direct arc.	Indirect arc.	Induc- tion.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
World.....	69½	20	10½
United States.....	89	9	2

Out of some 400 electric steel furnaces in the United States and Canada¹⁹ only four, or 1 per cent, are induction furnaces. About 5 per cent are indirect arc, the other 94 per cent being direct-arc furnaces. Out of some 150 furnaces in England only four are induction furnaces.

DRAWBACKS OF STEEL FURNACES FOR BRASS MELTING.

Induction furnaces of the ordinary horizontal-ring type will not melt brass, bronze, or similar copper alloys; their electrical resistance is so low that in order to introduce enough power for melting the current must be so high that the "pinch force"²⁰ comes into play and the conducting ring of metal no longer stays in place in the furnace. Hence the only types of steel furnaces that might be adapted to brass without material change are arc furnaces.

But the temperature of the carbon arc is about 3,500° C.,²¹ and the boiling points of various pure metals are given as follows:

Boiling points of various pure metals.

Metal.	Boiling point.			Metal.	Boiling point.		
	° C.	° C.			° C.	° C.	
Iron.....	^a 2,450	^b 2,450		Lead.....	1,525	1,640	1,555
Copper.....	2,340	2,350	^c 2,305	Antimony.....	1,440	1,440	1,330
Tin.....	2,270	2,260	2,270	Zinc.....	^d 920	920	930
Manganese.....	1,900	1,900					

^a Greenwood, H. C., The boiling points of metals: Trans. Faraday Soc., vol. 7, pt. 2, 1911, p. 151.

^b Johnston, J., The vapor pressure and volatility of several high-boiling metals: Jour. Ind. Eng. Chem., vol. 9, 1917, p. 876; Watts, O. P., The metals in order of their boiling points: Trans. Am. Electrochem. Soc., vol. 12, 1907, p. 141.

^c Raff, O. and Berglund, B., Researches at high temperatures: Ztschr. anorg. Chem., vol. 103, 1919, p. 16; Chem. Abstr. vol. 13, 1919, pp. 304, 3054.

^d Burgess, G. K., work cited, p. 438; compare Dewey, F. P., Volatilization in assaying: Min. and Met., No. 158, sec. 31, Feb., 1920; Met. and Chem. Eng., vol. 22, 1920, p. 797.

^{18a} Miller, D. D., Industrial heating as a central-station load: Supplement Society for Electrical Development, 1917.

¹⁹ Cline, E. F., The status of the electric steel industry: Iron Age, vol. 107, 1921, p. 69.

²⁰ Hering, C., The pinch phenomenon: Trans. Am. Electrochem. Soc., vol. 11, 1907, p. 329.

²¹ Burgess, G. K., Measurement of high temperatures: 1912, p. 454.

In a direct-arc steel furnace the arc is in contact with metal or with a comparatively thin layer of slag. Probably there is very little volatilization of iron in such a steel furnace, as the conduction of heat through the molten metal probably suffices to keep all save a very small portion of the bath below the boiling point; nevertheless, when ferromanganese is remelted in a furnace of the direct-arc type there is a high loss of manganese, unless the voltage of the furnace is so low that it runs more as a resistance furnace than a true arc furnace.²² Hansen²³ found a notable volatilization of copper in a direct-arc steel furnace for melting pure copper, and similar results have been reported by other observers; but lower-melting copper alloys have been melted in direct-arc furnaces with no trouble from copper vapor.

The approximate boiling points of copper-zinc alloys are shown in figure 1.²⁴ It seems probable that if a direct-arc steel furnace were used for melting a true copper-tin bronze there would be little loss by volatilization, because the boiling points of both metals are high. For alloys containing much lead or antimony some loss might be expected, and for alloys of copper with much zinc, such as yellow brass, the loss would be decided.

This is brought out still more clearly by Johnston,²⁵ who shows that the partial pressure of zinc vapor at 1,200° C. is about two and one-half atmospheres for 60:40 brass, two for 65:35, and one and one-half for 70:30.

For nickel or cobalt alloys not containing zinc, such as Monel, nichrome, chromel, and Stellite, the types of furnaces used for steel—direct arc, indirect arc, and horizontal-ring induction—are suitable, and all these types are used. Nickel brass, or German silver, however, more closely resembles brass and is not melted in the steel-making types.

Indirect-arc furnaces, in which the arc is struck over the metal, but in fairly close proximity to the bath, should show less loss by volatilization than direct-arc furnaces. However, as hot molten metal is lighter than colder molten metal, and as the arc must be above the bath, there is a possibility of the production of a superheated surface layer of metal on top of the bath, directly under the arc, so that the boiling point of the alloy may be exceeded in this layer and volatilization losses ensue.

²² Rodenhauser, W., *Ferromangan als Desoxydationsmittel*, 1915, p. 86.

²³ Hansen, C. A., Copper poisoning: *Met. Chem. Eng.*, vol. 9, 1911, p. 67; *Electric melting of copper and brass*: *Trans. Am. Inst. Metals*, vol. 6, 1912, pp. 122-125.

²⁴ Reprinted from *Bull. 73*, Bureau of Mines, figure 2, p. 129.

²⁵ Johnston, J., The volatility of the constituents of brass: *Jour. Am. Inst. Metals*, vol. 12, 1918, p. 20.

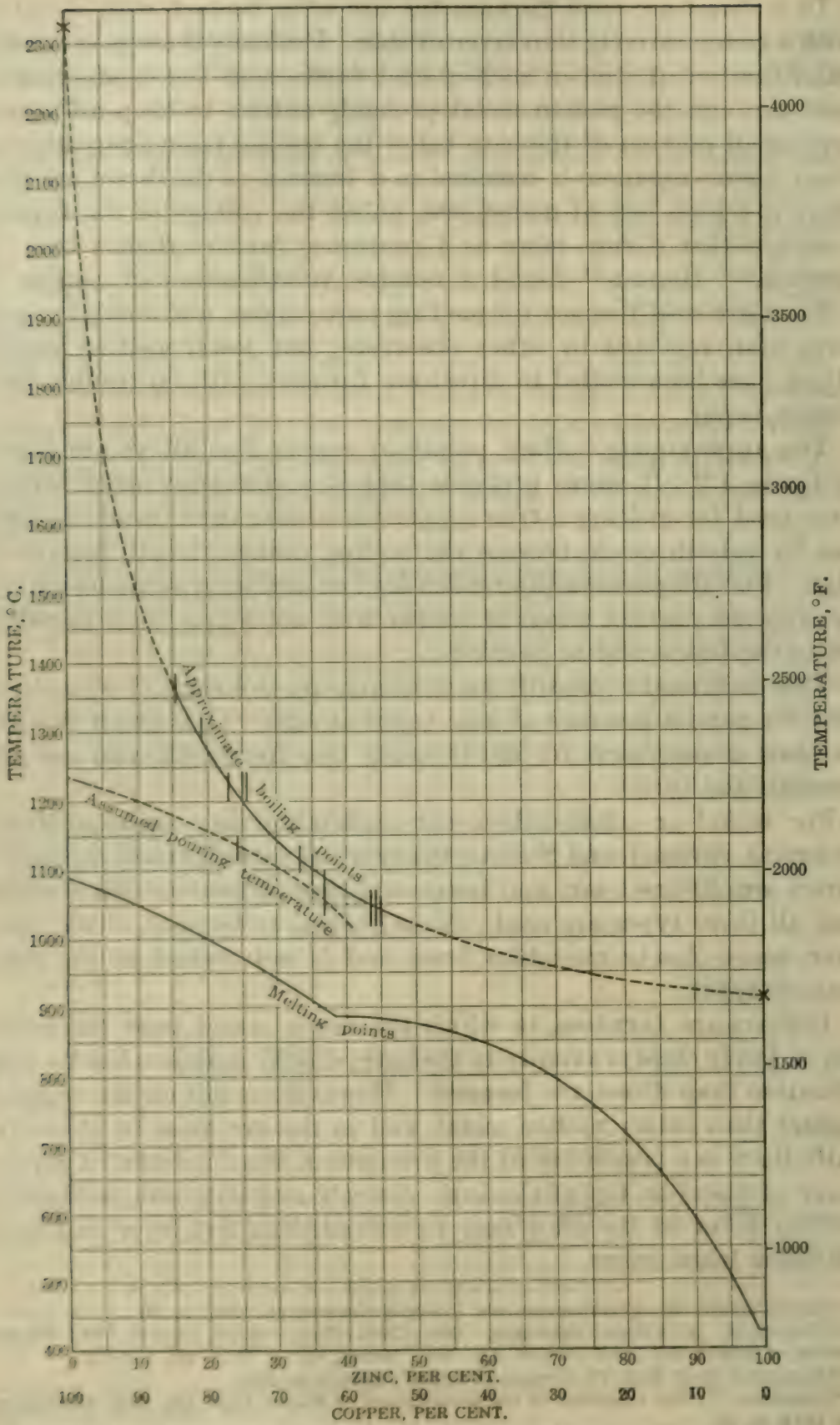


FIGURE 1. Approximate boiling points and assumed pouring temperatures of copper-zinc alloys.

It will be shown later that the applicability of the direct-arc and indirect-arc types of steel-melting furnaces to brass is limited for alloys with volatile constituents—just as the theory would indicate—and that to extend electric melting to such alloys it has been necessary to develop types of furnaces radically different from those in use for steel melting.

TYPES OF COMMERCIAL ELECTRIC MELTING FURNACES FOR STEEL.

All electric furnaces generate heat by the flow of current through a resistor, which may be solid, liquid, or gaseous. The gaseous-resistance furnace is, however, an arc furnace, which is the first subdivision usually made in the classification of electric furnaces.

If the arcs are drawn from carbon electrodes directly to the material to be heated, the furnace is a direct-arc furnace. If the arcs are drawn to a slag or to a material that has a relatively high resistance, the direct-arc furnace may become a combination arc-resistance furnace. In general, the arc heating so overbalances the resistance heating that the latter is negligible.²⁶

On the other hand, if the arc voltage is very low the resistance of the bath may be considerable in comparison with that of the arc. In the extreme case the voltage may be so low that there is no true arc, but merely a sort of contact resistance between the electrodes and the bath.

In practically all the arc, arc-resistance, and contact-resistance furnaces at least one electrode hangs vertically and its lower end is in close proximity to the bath.

Direct-arc furnaces may be (a) single phase with one top electrode and one bottom electrode making direct contact with the bath (Siemens,²⁷ Snyder,²⁸ Massip^{28a}); (b) single phase with two top electrodes (Heroult²⁹); (c) polyphase with two or more top electrodes and one bottom electrode, which may be in one piece or in several (Girod,³⁰ Mathusius,³¹ Snyder,³² Gronwall-Dixon,³³ Greaves-Etch-

²⁶ Rodenhauser, W., and Schoenawa, J., translated by vom Baur, C. H. [Electric furnaces in the iron and steel industries], 1917, p. 80.

²⁷ Siemens, W., English Patent 2,110 of 1879.

²⁸ Snyder, F. T., U. S. Patent 1,167,026, Jan. 4, 1916.

^{28a} Massip, G., U. S. Patent 1,080,840, Dec. 9, 1913.

²⁹ Heroult, P. L. T., U. S. Patent 707,776, Aug. 26, 1902.

³⁰ Girod, P., U. S. Patent 921,228, May 11, 1909; Buck, C. C., The Bethlehem 10-ton Girod steel furnace: Trans. Am. Electrochem. Soc., vol. 31, 1917, p. 81.

³¹ See Rodenhauser, W., Ferromangan als Desoxydationsmittel, 1915, p. 50.

³² Industrial Electric Furnace Co., Electric Furnace Bulletin, October, 1917; Snyder, F. T., U. S. Patent 1,327,174, Jan. 6, 1920.

³³ Crowley, J. A., The Gronwall-Dixon electric furnace: Foundry, vol. 44, 1916, p. 497; Dixon, J. L., U. S. Patent 1,198,626, Sept. 19, 1916.

ells,⁴¹ Greene,⁴² Booth-Hall,⁴³ Moore,⁴⁴ Webb,⁴⁵ Keller⁴⁶); (*d*) poly-phase, three or more top electrodes, no bottom electrode (Heroult,⁴⁰ Burke,⁴¹ Ludlum,⁴² vom Baur,⁴³ Price-Dixon,⁴⁴ Snyder,⁴⁵ Masera,⁴⁶ and Dryssen⁴⁷).

In all types with a bottom electrode that electrode may be of conducting material, such as carbon or metal, or may be of a second-class resistor; that is, one that conducts only when hot, as magnesite.

Of arc-resistance furnaces, or resistance furnaces structurally similar to direct-arc furnaces, the examples are fewer. They include the Wile, shaft,⁴⁸ and tilting,⁴⁹ and the Schemman and Bronn.⁵⁰ Of indirect-arc furnaces, with the arc struck between carbon electrodes over the metal bath, the commercial examples are the Rennerfelt,⁵¹ two-phase, and Stassano,⁵² three-phase.

A résumé of present electric steel practice is given by Diller.⁵³

The various induction furnaces that have had commercial use (Colby, Kjellin, Frick, Roechling-Rodenhauser) are described by Rodenhauser and Schoenawa⁵⁴ and by vom Baur.⁵⁵

⁴¹ See Rodenhauser, W., and Schoenawa, J., translated by vom Baur, C. H., work cited, p. 26.

⁴² Rolling cylinder electric steel furnace: *Foundry*, vol. 44, 1918, p. 339.

⁴³ Booth, W. K., The Booth-Hall electric furnace: *Trans. Am. Electrochem. Soc.*, vol. 23, 1918, p. 95.

⁴⁴ Acheson Graphite Co., Electric furnaces made in the United States, September, 1919, pp. 19, 14; Moore, W. E., U. S. Patent 1,304,350, May 20, 1919.

⁴⁵ Industrial Electric Furnace Co., Electric Furnace Bulletin No. 40, 1917, p. 10.

⁴⁶ Stahl, H. A., The electric furnace 1914 ed. p. 223.

⁴⁷ See Rodenhauser, W., and Schoenawa, J., translated by vom Baur, work cited.

⁴⁸ Burke, J., U. S. Patent 1,082,459, Dec. 23, 1913.

⁴⁹ Sawhill, R. V., Melting all scrap in the electric furnace: *Foundry*, vol. 45, 1917, p. 339.

⁵⁰ vom Baur, C. H., The vom Baur arc furnace: *Trans. Am. Electrochem. Soc.*, vol. 23, 1918, p. 137; U. S. Patents 1,252,633, Jan. 8, 1918, and 1,385,411, July 26, 1921.

⁵¹ Acheson-Graphite Co., Electric furnaces made in the United States, p. 11.

⁵² Industrial Electric Furnace Co., advertisement: *Foundry*, vol. 48, 1920, Feb. 15, p. 61.

⁵³ Masera, C., U. S. Patent 1,320,884, Nov. 4, 1919.

⁵⁴ Dryssen, W., U. S. Patent 1,317,911, Oct. 7, 1919.

⁵⁵ Wile, R. S., U. S. Patent 947,723, Jan. 25, 1919.

⁵⁶ Wile, R. S., U. S. Patent 1,070,568, Aug. 19, 1913.

⁵⁷ Schemmann, W., and Bronn, J., U. S. Patent 1,056,450, Mar. 18, 1913; see also Rodenhauser, W., *Ferromangan als Desoxydationsmittel*, 1915, p. 26.

⁵⁸ Rennerfelt, L., U. S. Patent 1,076,518, Oct. 21, 1913; vom Baur, C. H., The Rennerfelt electric arc furnace: *Trans. Am. Electrochem. Soc.*, vol. 29, 1916, p. 497; Rennerfelt electric furnace operation: *Trans. Am. Electrochem. Soc.*, vol. 31, 1917, p. 87; Rodenhauser, W., and Schoenawa, J., translated by vom Baur, C. H., *Electric furnaces in iron and steel industry*, 1917, p. 161.

⁵⁹ Stassano, E., U. S. Patents 799,105, Sept. 12, 1905; 1,024,657, Apr. 30, 1912; 1,055,496, Apr. 22, 1913; and 1,165,859, Aug. 4, 1914; see also Rodenhauser, W., and Schoenawa, J., work cited, p. 106.

⁶⁰ Diller, H. E., *Polymers on electric steel furnace practice*: *Foundry*, vol. 47, 1919, p. 239; see also Siede, J. A., *Electric furnaces for production of steel and ferro alloys*: *Gen. Elec. Rev.*, vol. 21, 1918, p. 767; Moore, W. E., *Electric furnaces for steel foundries*: *Iron Ind.*, vol. 16, 1919, p. 360; Lindemuth, L. B., The position of the electric furnace in iron and steel metallurgy: *Trans. Am. Electrochem. Soc.*, vol. 37, 1920, p. 611.

⁶¹ Rodenhauser, W., and Schoenawa, J., work cited, p. 173 ff.

⁶² Vom Baur, C. H., *Electric induction furnaces for steel*: *Trans. Am. Electrochem. Soc.*, vol. 22, 1912, p. 117.

A recent modification made by the General Electric Co. is described by Unger and Scharschu.⁵⁶

Of all these various types and makes of steel furnaces only two—the Snyder and the Rennerfelt—have had appreciable commercial application to brass or bronze, and the use of these two is strictly limited to alloys low in zinc. Other types and makes are used in melting nickel alloys.

TYPES OF BRASS FURNACES.

A great variety of designs, many of them markedly different from steel-furnace designs, have therefore been tried or suggested for brass and bronze, as has been shown in Table 2.

Electric brass furnaces should be considered first as brass furnaces and second as electric furnaces; that is, the user is concerned with quality, rate of production, and cost of production rather than with kilowatt hours, power factor, load factor, volts, and amperes.

The electrical characteristics of the furnace, however, affect its reliability, its efficiency, and thus its operating cost, as well as its desirability as a load for the power plant or the central station, and therefore should be considered. For this reason electric brass furnaces have to be classified not only in regard to their behavior as brass furnaces but also in regard to the means by which they generate heat from the electric current. They will be discussed under the following heads:

A. Crucible furnaces (with few exceptions, of the carbon resistance type).

a. Lift-out.

b. Tilting.

B. Hearth or noncrucible furnaces.

a. Carbon resistance, radiated-heat type.

b. Arc furnaces.

I. Smothered arc.

II. Direct-arc type.

α. Stationary furnace.

1. Open arc.

2. Arc to slag or slag resistance.

3. Low-voltage arc or contact resistance.

β. Moving furnaces.

III. Indirect-arc type.

α. Stationary furnaces.

β. Moving furnaces.

⁵⁶ Unger, M., and Scharschu, C. A., New type of induction electric furnace: *Iron Age*, vol. 108, 1921, p. 344.

c. Internal metallic resistance furnaces.

α. Horizontal-ring induction.

β. Pinch-force resistor.

γ. Vertical-ring induction.

δ. High-frequency, eddy-current induction.

OPERATION OF ELECTRIC BRASS FURNACES DOES NOT REQUIRE AN ELECTRICAL ENGINEER.

Although constant reference has to be made to electrical terms in describing electric brass furnaces, and these terms are defined in this report, there should be no misconception as to the amount of electrical knowledge necessary for the operation of electric brass furnaces.

One does not have to be an electrical engineer to understand the operation of an electric furnace any more than one has to be an automotive engineer to understand the operation of an automobile. Several types of commercial electric brass furnaces have been operated regularly and satisfactorily by negro crews. Even the superintendent of a brass foundry using electric furnaces need concern himself but slightly with the purely electrical side of the installation. An electric-furnace load is, generally speaking, so desirable to a central electric generating station that the station, if consulted in the choice and during the installation of the furnaces, will gladly supply all needed electrical advice. Central stations on the lookout for desirable loads have contributed much to the development of the commercial use of electric brass furnaces.

If the electric furnace is built and installed by a furnace maker who has the proper combination of electrical engineering knowledge, electric furnace experience, and acquaintanceship with brass melting and brass foundry problems—the last factor is by no means the least important—he should be able, during the time he spends in teaching the foundry force to run the furnace, to impart to them all the electrical knowledge necessary. With the engineers of the local central station⁵⁷ eager to assist in the solution of problems that might arise

⁵⁷ Compare St. John, H. M., Commercial testing of metallurgical electric furnaces: *Chem. and Met. Eng.*, vol. 21, 1919, p. 377; The present status of electric brass melting: *Elec. World*, vol. 1, 1918, pp. 1129, 1216; Electric brass melting from the central station viewpoint: *Trans. Am. Inst. Metals*, vol. 9, 1915, p. 395; Crosby, E. L., The present status of the electric furnace: paper at Central Station Sales Managers' Assn. Meeting, August, 1914; Electric furnaces and the central station: *Elec. Rev.*, vol. 74, 1919, p. 799; Electric furnaces and industrial foundries: *Elec. Rev.*, vol. 75, 1919, p. 1022; Smith, A. C., The electric-arc melting furnace and the central station electric company: *Trans. Am. Electrochem. Soc.*, vol. 37, 1920, p. 701; Wilcox, E. A., Electric power from the standpoint of the central station: *Trans. Am. Electrochem. Soc.*, vol. 37, 1920, p. 589; Wirtz, H. A., The electric melting furnace as a central station load: *General Electric Rev.*, vol. 24, 1921, p. 510.

in their field, no foundry need refrain from installing an electric brass furnace merely because its force does not include an expert in electrical theory.

TERMINOLOGY AND FUNDAMENTAL ELECTRIC PRINCIPLES OF ELECTRIC FURNACES.

In describing and discussing electric furnaces it is, however, necessary to use certain electrical terms, and in order to comprehend the action of the furnaces some of their governing principles should first be understood. These terms and principles are given below, briefly; rigid definitions are not attempted. For further details standard works should be consulted.⁵⁸

An *electric furnace* is a device in which electrical energy is changed into heat.

An *electric current* is a flow of electricity. It can not be exactly defined. It is measured in *amperes*, which give the rate of flow of the current.

Direct current, or D. C., is current that flows in one direction only, as in a storage battery. It is not used in any electric brass furnace.

Alternating current, or A. C., is a current that flows first in one direction and then in the other. All electric brass furnaces except one utilize alternating current. The rate at which alternating current reverses its direction is the *frequency* or *periodicity* of the current. Usually alternating current is 60-cycle; that is, it reverses its direction 60 times per second; 25-cycle is sometimes, and 40-cycle rarely, used. *High frequency* current, as used in only one furnace, may go up to 25,000 cycles. This one furnace may also use *oscillatory current* in which a discharge gap is used, through which current flows at short intervals. While the current flows it oscillates back and forth. The oscillatory-current system for this one furnace requires *condensers*, which are devices for the storage of one type of electric energy.

An *electric circuit* is the path of the current. The unit of electric current is the *ampere*.

⁵⁸ Stansfield, A., *Electric furnaces as applied to nonferrous metallurgy*: Jour. Inst. Metals (British), vol. 15, 1916, p. 301; *The electric furnace*, 1914 ed.; Rodenhauser, W., and Schoenawa, J., translated by vom Baur, C. H., *Electric furnaces in the iron and steel industry*, 1917 ed.; Roland, A. I., *Applied electricity for practical men*, 1916 ed.; Fowle, F. F., *Standard handbook for electrical engineers*, sect. 19; Kent, R. T., *Mechanical engineers' pocketbook*; Marks, L. S., *Mechanical engineers' handbook*, sec. 14; Lyon, D. A., and Keeney, R. M., *Electric furnaces for making iron and steel*: Bull. 67, Bureau of Mines, 1916, 144 pp.; Lyon, D. A., Keeney, R. M., and Cullen, J. F., *The electric furnace in metallurgical work*: Bull. 77, Bureau of Mines, 1916, 216 pp.; Seede, J. A., *Electric furnaces*: Gen. Elec. Rev., vol. 11, 1914, p. 653; *Electric-furnace control*, vol. 13, 1916, p. 501; Society for Electrical Development, *Industrial heating as a central-station load*, pt. 1, *Electric furnace*: Bull., 1917; St. John, H. M., *Electric brass melting, its progress and present importance*: Elec. Jour., vol. 16, 1919, p. 373; *The evolution of the electric brass furnace*: Iron Age, vol. 105, 1920, p. 1223; Trans. Am. Electrochem. Soc., vol. 37, 1920, p. 161; *The influence of the electric furnace on the metallurgy of the non-ferrous metals*: Trans. Am. Electrochem. Soc., vol. 40, 1921 (not yet published); Snyder, E. T., *A B C of iron and steel*, Chapt. XVIII: *Electric steel*, 1915, p. 253; West, C. J., *The electric furnace as applied to metallurgy (Bibliography, 1900-1919)*: Trans. Am. Electrochem. Soc., vol. 37, 1920, p. 461; Acheson Graphite Co., *Brass melting* (pamphlet): Aug., 1920; B. M. J., *Electric furnaces for brass melting*: Mech. World (Manchester, England), vol. 67, 1920, pp. 5, 105, 198.

The *volt* is the unit of electrical pressure and is the electrical analogue of hydrostatic head in fluids. The *voltage* is the measure of the force that urges the current to flow.

Electric power is transmitted with the least loss at high voltages, hence much long-distance transmission is done at voltages as high as 66,000 volts or more.

Transmission voltages from near-by central stations are usually 6,600, 4,400, or 2,200 volts. The voltage used on the electric brass furnaces themselves is much lower, being usually not over 120.

Electrical power is the rate of use of electrical energy and is measured in *watts*. One thousand watts equals 1 kilowatt (kw.). A furnace is rated in kilowatts as to its ability to absorb power. *Electrical energy* is that which is transformed into heat in the electric furnace. It is electrical power used for a definite time and is measured in watt hours, or in commercial furnace work in kilowatt hours (kw. h.). A kilowatt hour is the unit by which electric energy is paid for. One kilowatt hour, for furnace use, usually costs between 1 and 2 cents. One kilowatt hour equals 3,412 B. t. u.

Power factor (P. F.) is a number not greater than 1, by which the *apparent* power (volts $\times$ amperes) has to be multiplied to give the *real* power (watts).

Where the power factor is unity, volts $\times$ amperes $\times$ 1,000=kilovolt amperes (kv. a.)=kilowatts. Where it is less than unity, volts $\times$ amperes $\times$ 1,000 $\times$ power factor=kilovolt amperes $\times$ power factor=kilowatts. The power factor is always unity with direct current; it is nearly unity in most resistance furnaces, seldom unity in electric-furnace leads, is usually around 0.80 to 0.90 (usually written 80 to 90 per cent or 80 to 90, 100 being taken as unity power factor) in arc furnaces, and is likely to fall lower in induction furnaces. It is sometimes denoted by $\cos \Phi$. Central stations usually charge a "penalty" in their power bills when the power factor falls below 70. Most electric induction-motor loads have a power factor not much above 70, so that electric-furnace loads are usually better for the central station than many motor loads. A low power factor does not mean that more water must flow through a turbine or more coal be used in the generation of the power, but it means that more amperes flow through the circuit. Larger wires and bigger generating machinery are required to carry this excess current that does not become changed into heat in the furnace.

Alternating current is usually so generated and transmitted that more than one current flows in the same system. Each branch of these currents is called a *phase*. Common commercial alternating current is three phase, carried on three wires. Two-phase systems, carried on either three or four wires, are sometimes used, but the three-phase three-wire system is most common. In it each of the three, currents travels on two of the wires, or, when connected in another way, on all three wires.

One current only—that is, single-phase power—may be taken off of two wires. Unless an equal amount is taken off of the other two phases at the same time the full capacity of the three-phase generator will not be utilized.

If a large variable load is taken off of one phase of a small generator, the generator will not be able to maintain proper conditions on the other two phases. The permissible single-phase load that can be taken off a three-phase circuit depends on the capacity of the generating or distributing system. In a large generating system a 300-kw. single phase load is not often objectionable. Where a plant generates its own power from one small generator, a much smaller single-phase load might be impossible to handle. Most plants that melt brass, however, take their power from large generating systems that can handle large single-phase loads; and since electric brass furnaces seldom draw over 300 kv. a., the great majority of such furnaces are single phase, as they

are electrically simpler. A few two-phase furnaces are used, but very few three-phase brass furnaces are now in commercial operation. In steel furnaces the situation is just the reverse, the vast majority being three phase, only a few being run on two-phase or single-phase systems.

The power used in a balanced three-phase three-wire system is not $3 \times \text{volts} \times \text{amperes} \times \text{power factor}$, but $\sqrt{3} \times \text{volts} \times \text{amperes} \times \text{power factor}$. Three-phase power can be transformed to two-phase by a special connection of the transformers known as the *Scott connection* and the three-phase load still kept sufficiently balanced. Three-phase power can not be transformed into single phase and keep the three-phase load balanced save by the use of a three-phase motor, single-phase generator set.

A *transformer* is a device having primary and secondary coils by which power at one voltage and amperage is changed without much loss into power at another voltage and amperage; for example, a transformer may take 6,600-volt current at 34 amperes on the primary and deliver it to a furnace at 110 volts and 2,000 amperes on the secondary. The transformer may have several *taps*, from each of which a different voltage may be taken. An *autotransformer* is a type adapted for use when little change of voltage is needed.

Current is carried on *conductors*, where its conversion into heat is not desired, and carried through *resistors* where it is to be so converted.

Conductors, such as copper, allow current to pass readily; *resistors*, like crushed carbon, allow it to pass with difficulty and generation of heat results; and *insulators*, such as cold porcelain, practically do not allow current to pass at all, though, strictly speaking, there is no perfect insulator.

The *resistance* of a material through which current flows is the opposition it presents to that flow. Resistance is measured in *ohms*. $\text{Amperes} = \frac{\text{volts}}{\text{ohms}}$ (Ohm's law).

The resistance of metals increases with increase of temperature, while that of the nonmetallic conductors, as carbon, graphite, carborundum, and most liquids other than molten metals, decreases with increase of temperature. Some insulators become resistors or even conductors (sometimes called second-class conductors) when heated, as magnesite. It is usually necessary to heat to redness or above. The resistance of these materials falls with increasing temperature; they belong to the class of nonmetallic conductors.

Conductors used to carry the current to electric furnaces may be *wires*, *cables*, or *bus bars*, according to their size and shape. *Leads* is a general term for large conductors carrying heavy currents to furnaces.

The current is brought into and taken out from the furnace itself by *electrodes*, which make connection between the leads and the resistor. The latter may be gaseous—that is, an arc—a solid, or a liquid. The end of an electrode where it joins the resistor is hot; where it joins the lead it is cool. Electrodes for commercial brass furnaces are usually graphite or carbon, rarely copper; if the electrodes are copper they are molten where they join the resistor and are water cooled to keep them solid where they join the leads. Graphite electrodes are also usually water cooled at this point. All electric furnaces except induction furnaces require electrodes.

Resistors may be solid, liquid, or gaseous. The filament in an incandescent lamp and the vapor in a mercury-vapor lamp are resistors. A furnace using a vapor as a resistor is an *arc furnace*. In a *direct-arc* furnace the arc is drawn from an electrode directly to the material to be melted or to other material on top of it. In an *indirect-arc* furnace the arc is drawn from one electrode to another, but not to the material to be heated. In either type, with carbon or

graphite electrodes, the gaseous resistor is largely carbon vapor, derived from the electrode, which is therefore slowly used up. It may also contain the vapor from any other sufficiently volatile material in the neighborhood.

A strictly *resistance furnace* has a solid or liquid resistor. Furnaces with liquid resistors usually fall into other classes as well, so that a resistance furnace usually means one with a solid resistor. The resistor may be divided into parts, and the contact resistance between the parts may be much greater than the resistance of the solid material, as granular resistors and resistors made of piles of carbon plates. The resistance of a conductor or resistor increases as the length is increased or as the cross section is decreased. The heat generated in a resistor (or in a conductor) is proportional to the square of the current and directly proportional to the resistance, as well as to the time the current passes: $\text{Heat} = (\text{current})^2 \times \text{resistance} \times \text{time}$ (Joule's law).

As (power factor being disregarded) power is the product of current times voltage, a 200-kilowatt furnace could take 2,000 amperes at 100 volts or 4,000 amperes at 50 volts. There are always some losses from heat generated by the current outside the furnace in leads and electrodes. As the heat thus generated is proportional to the square of the current, the higher the current and the lower the voltage the harder it is to keep these losses low. Other things being equal, a furnace with a high voltage and a low current has an advantage over one of low voltage and high current. On the one hand, the voltage must be kept low enough not to be dangerous to life, preferably not more than 220 volts. On the other hand, the current must be low enough not to necessitate large and expensive leads and electrodes for holding the current density sufficiently low outside the furnace to prevent loss of power by heating.

Current density is the amperes per unit (square inch) of cross section of a resistor or conductor. Current density is usually around 500 amperes per square inch in copper conductors and 100 to 200 amperes per square inch in graphite electrodes. At very high current densities in large leads the current tends to flow more on the outer parts of the lead and less in the center. This is called the "skin effect." If the current density is high enough, as 5,000 amperes per square inch, in an induction furnace, a conductor, like brass, may become a resistor. An *induction furnace* is a type of transformer in which the secondary consists of one coil only, this being the charge itself. The secondary is also a resistor, so that an induction furnace is a form of resistance furnace.

The generation of current in the secondary of an induction furnace or of a transformer is due to the presence of a *magnetic field* containing *lines of force* in the vicinity of a conductor; that is, the primary. With each change of direction of an alternating current this magnetic field ceases to exist and is then reformed. This change or *flux* in the magnetic field makes the lines of force pass across the secondary, and in passing they *induce* or generate current in the secondary. The magnetic field is strongest—that is, the lines of force closest together—at points nearest the primary. The secondary, therefore, must be close to the primary and so placed as to cut all possible lines of force.

If any lines of force escape without being cut, these escaping lines do no work, so that the apparent power taken from the primary is less than the real power sent to the secondary; that is, a transformer or induction furnace that allows magnetic leakage has a low-power factor, less than unity, and sometimes, in a furnace, the power factor is very low.

In order to force or coerce the lines of force to take a regulated path an iron *core* is provided to interlink the primary and secondary, since the magnetic flux can travel more readily in iron than in air.

Proximity of leads carrying heavy currents to structural ironwork or other iron tends to cause loss of energy through magnetic and other losses, may affect adversely the power factor of the whole furnace installation, and may even make impossible the transmission of the proper amount of power to the furnace. The mutual effect of the currents in different leads may have a similar effect, which can be minimized by interlacing the leads properly.

Eddy currents or *Foucault currents* are set up in magnetizable conductors, such as iron, which are subjected to cyclic magnetization by being in the field of force of a conductor carrying alternating current. They flow more readily in solid conductors than in laminated ones, so the cores of transformers and induction furnaces are made up of piles of thin iron sheets. Magnetic eddy currents cause heating just as alternating current does. They are small in magnitude when the frequency of magnetization is low, so eddy-current losses are usually not great with ordinary 60 or 25 cycle power. With high-frequency current, around 12,000 to 25,000 cycles, the heating may be great, and it is utilized in one type of electric brass furnace. The magnetization set up in iron and steel or in another conductor near a conductor carrying heavy currents may be considerable, so that in the design of a furnace and in the installation of the leads care must be taken to avoid this.

When the power factor is low, whatever the immediate cause may be, the underlying cause is the presence in the circuit of *reactance*. Reactance is analogous to resistance; it impedes or tends to hold back the flow of current and makes the waves of alternating current reach their peak at a different instant from the waves of voltage. Reactance may be intentionally added to the circuit and, if properly chosen, may be so proportioned to the resistance of the circuit as not to interfere materially with the flow of current of a certain strength; that is, it does not greatly reduce the power factor at that current strength, but interferes more and more as the current is increased, until finally the current can no longer increase. This prevents too great surges of current in the circuit. In arc furnaces the arc must be started by barely making connection between the electrodes, with a poor contact. Heat is generated at this poor contact until carbon enough is vaporized to form a gaseous resistor; then an electrode is pulled out of contact with the other electrode and the current is carried thereafter by the vapor. Excessive current may flow while the electrodes are in contact if the reactance of the circuit is low. In a certain arc furnace, normally operating at about 1,700 amperes, a current of 13,000 amperes flowed when the electrodes were touched together. After the insertion of a little reactance in the circuit the maximum short-circuit current was only 4,000 amperes.

Properly chosen current-limiting reactances are useful in arc furnaces, but undesirable reactance should be avoided in all furnaces and especially in the leads. This problem is, in general, one for the attention of the furnace maker when he builds and installs the furnace rather than for the operator.

A *short circuit* is the joining, by a path having much lower resistance, of two parts of a circuit which should have considerable resistance between them, as would result from dropping an iron bar against two electrodes of an arc or resistance furnace. The bar would allow excessive current to flow and perhaps burn out the transformer or cause other damage. Furnaces should be so designed that accidental short circuits can not readily occur.

Circuit breakers usually are installed to protect the line against short-circuits or other overloads.

When two or more things that can carry current, whether conductors, electrodes, or resistors, are one after the other in the same circuit, they are said

to be in series. When they are side by side or so arranged that the current passes through two or more branches, they are said to be *in parallel*.

Current (amperes), voltage (volts), power (kilowatts), energy (kilowatt hours), and power factor may all be measured by *meters* (ammeters, voltmeters, etc.), which, as well as the switches by which a circuit is made or cut, the circuit breakers, etc., are generally mounted on a *switchboard*. The meters required vary with the type of furnace, but some meters are needed for the operation of any furnace.

Demand meters, as well as kilowatt-hour meters, may be installed by the central station on the readings of which the power bill is made out, but the former are not usually a part of the equipment of the furnace. The central station's kw.-h. meter usually reads all the energy for lights, motors, and furnaces that is used in a plant, being placed on the main feed line to the plant, and thus registering the power used on the high-tension side of the transformers and including the losses in them. They can seldom be read as closely as is required for use in furnace operation. Each furnace should therefore have its individual kw.-h. meter on its own switchboard. It may be that this meter can not conveniently be installed to record the power used on the high-tension side of the transformer and thus to include the losses of power in transformer and leads; then it does not show the total amount of power to be paid for. The furnace maker or the central station in that case should be asked to determine the ratio between the readings of the furnace meter and the total energy required by the furnace plus the transformer and lead losses.

Some furnaces are provided with *automatic electrode control* in order to reduce the labor of operating the furnace and to maintain the proper power input. These controls are purely electrical devices and their consideration in this paper would lead the reader too far afield.

Other electrical terms used are either self-explanatory or will be explained when used.

The fundamental principles of furnace design for thermal efficiency are the same for electric as for fuel-fired furnaces. They will be brought out in the discussion of individual furnaces.

FACTORS IN THE APPLICABILITY OF ELECTRIC FURNACES.

As has already been pointed out⁵⁹ in regard to fuel-fired furnaces, no one type or size of furnace can meet properly all the various conditions under which nonferrous alloys are melted. It is therefore necessary, by the study of data, to determine for a given set of conditions, (1) whether any electric furnace is preferable to fuel-fired furnaces; (2) if so, what type will best serve; and (3) how it should be operated to produce the best results.

The main points to consider are⁶⁰ metallurgical results, quality of product, electrical characteristics, reliability and rate of production, thermal efficiency, and costs of operating and maintenance. These phases of the subject will be discussed for each type of furnace.

⁵⁹ Gillett, H. W., Brass-furnace practice in the United States: Bull. 73, Bureau of Mines, 1914, p. 16; Eastick, T. H. A., Melting furnaces: Metal Ind., vol. 18, 1920, p. 319.

⁶⁰ Compare St. John, H. M., Commercial testing of metallurgical electric furnaces: Chem. and Met. Eng., vol. 21, 1919, p. 277.

CRUCIBLE FURNACES IN GENERAL.

No carbon-resistor crucible furnace has had any real success in brass melting; all the furnaces commercially used are of the non-crucible or hearth type. The necessary requirements for a successful hearth-type furnace will be given when that type is discussed.

Electric crucible furnaces will be described first, as they were the first type to be tried out. The furnaces are not discussed in chronological order, but in the order of their classification in Table 2.

In nonferrous melting with fuel-fired furnaces, crucible furnaces have been used because they gave a high-grade product. There is no contact with fuel, as compared to a cupola, and little contact with products of combustion, as compared to the reverberatory or direct flame (oil or gas) furnaces. Little surface is exposed as compared to the reverberatory type, and usually the passage of products of combustion is slower over the exposed surface. Avoidance of an oxidizing atmosphere is fairly easy, and as the heating is mainly from the bottom upward a thermal circulation which does some mixing is started by the rising of the hot metal. Crucibles have been used for producing alloys of high quality, free from oxygen and sulphur, and for melting brasses high in zinc in order to avoid volatilization of that element. Metal losses in melting are lower and the quality of the product higher, generally speaking, than in the reverberatory type of furnace.

These advantages are gained by sacrificing speed of production, by increasing the labor cost, because the capacity of the average crucible is small, and by making the fuel cost high because of the extremely low thermal efficiency of a crucible furnace.

It is improbable that electrically heated crucible furnaces will be used much commercially (1) because the advantage of crucible melting in quality of product can usually be obtained in electric furnaces without using crucibles; (2) because crucibles are fragile and costly; and (3) because more energy is required to melt metal in a crucible than is required to melt it by applying the heat directly, not passing it through the crucible wall.

One of the fundamental principles⁶¹ in the design of brass furnaces, especially electric brass furnaces, is that unless some strong reason forbids, the source of heat should be as close to the material to be heated as possible and should be separated from it (if it can not be in contact with it) only by a material that will least resist the flow of heat. For the temperature in question a gaseous atmosphere offers less resistance than any solid or liquid.

⁶¹ Compare Johnson, W. McA., and Sieger, G. N., *Electric furnaces, their design, characteristics, and commercial application*: Met. and Chem. Eng., vol. 11, 1913, p. 505; Ray, W. T., and Kreisinger, H., *The flow of heat through furnace walls*: Bull. 81, Bureau of Mines, 1911, 80 pp.

It is about as reasonable to heat a brick house by building a fire against the walls outside instead of within the house as to use an externally heated crucible for brass melting if a more direct application of heat is possible.

Another principle of furnace design is that, as some of the heat supplied is lost by radiation from the walls or in similar ways, the wall area should be as small as possible in comparison to the volume of metal to be melted. This object can be accomplished by avoiding waste space within the furnace or by increasing the size, and hence the ratio of capacity, to the wall area in a given style of furnace. Furnaces to take a single crucible have small capacity in comparison to wall area, and those to take a number of crucibles usually have much waste space inside. It is not surprising, then, that no electric crucible furnace for brass has proved commercially valuable. This will become obvious as different crucible furnaces are considered.

DESCRIPTION OF CRUCIBLE FURNACES—LIFT-OUT TYPE AND THEIR PERFORMANCE.

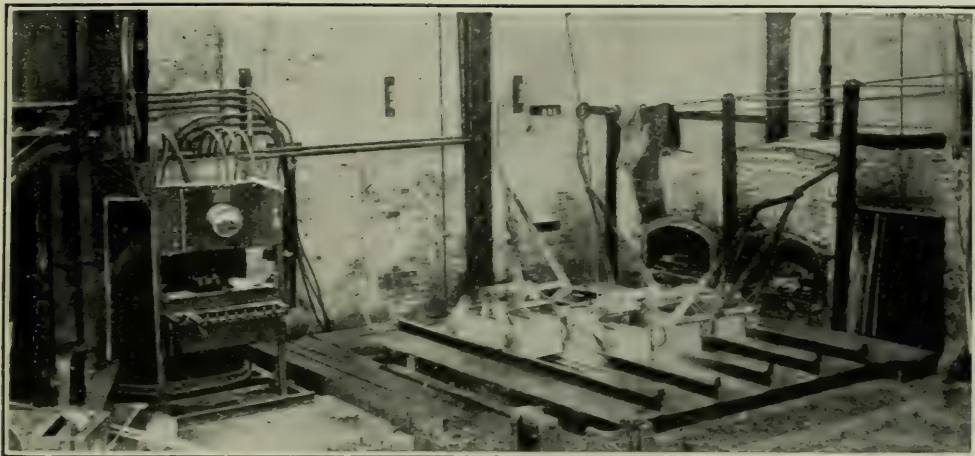
FITZGERALD FURNACE.

Fitzgerald⁶² in 1905 described a crucible furnace for experimental work and in 1915 constructed one for the Titanium Bronze Manufacturing Co., of Niagara Falls, which is described by Vickers,⁶³ with detailed drawings.

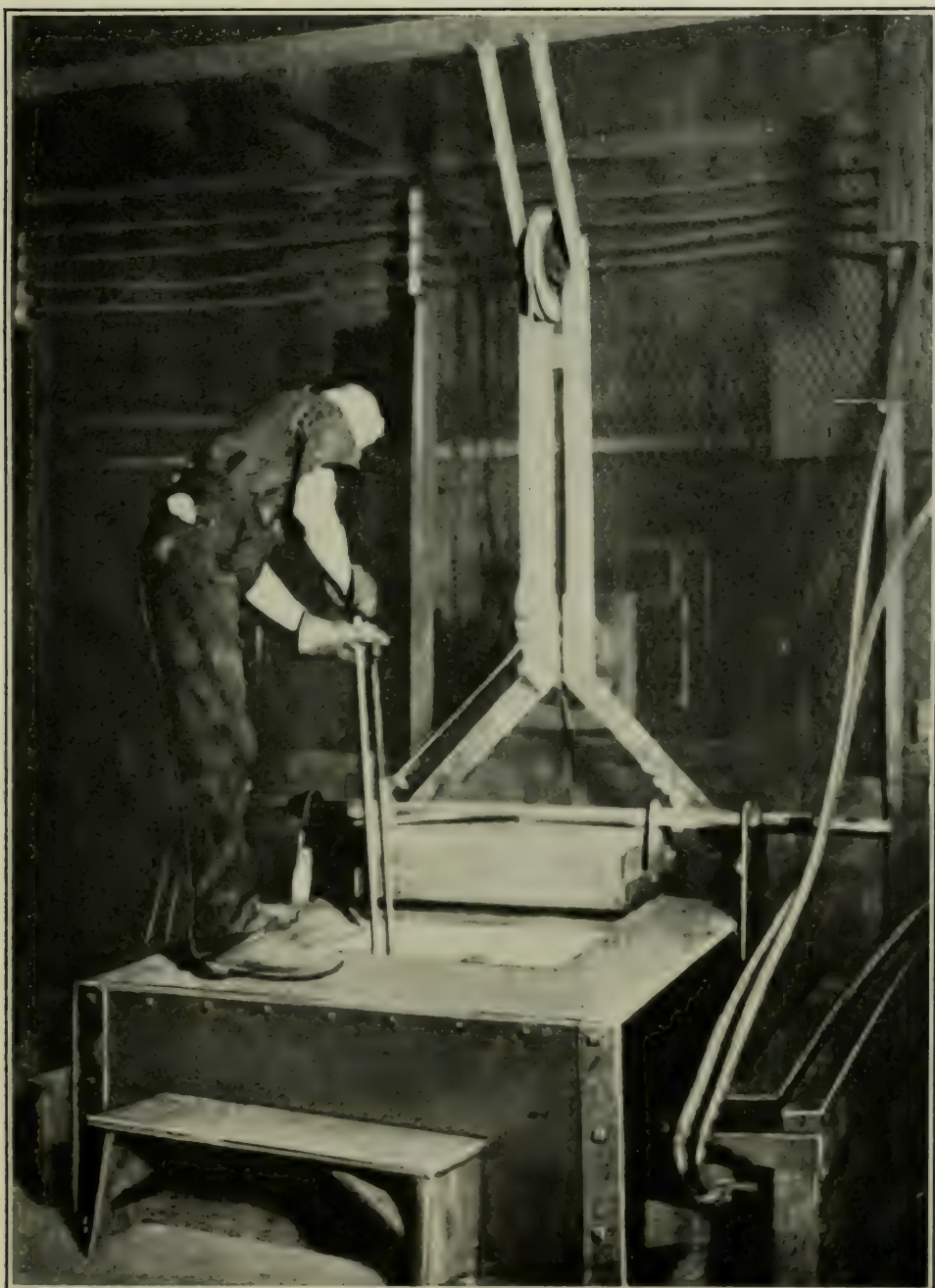
This furnace was made to take two No. 50 crucibles, but as the electrodes projected above the furnace and interfered with pulling the pots much smaller pots were used, the heats cited being of but 25 pounds. The furnace was set in the ground like an ordinary pit furnace. There were two cylindrical melting holes, each 15 inches in diameter by 20 inches high, in which the crucibles were set; these holes had walls made of carborundum fire sand and a bond rammed into place, that were 1½ inches thick and were surrounded by 4 inches of crushed coke to serve as resistor. Carborundum fire sand was placed between the annular resistor space and the fire-brick walls of the furnace. The two annular spaces were joined, so that the current entered the furnace by one electrode at each end, ran in parallel around both sides of the resistor about one melting hole, then around the other resistor, and out the other electrode at the opposite end of the furnace. Suitable heat-insulating bricks were placed around the sides, top, and bottom of the furnace, and pits were provided below to catch the metal if a crucible broke.

⁶² Fitzgerald, F. A. J., Resistance furnace for crucibles: *Electrochem. and Met. Ind.*, vol. 2, 1905, p. 55.

⁶³ Vickers, C., Electric furnace as a copper-melting medium: *Foundry*, vol. 45, 1917, p. 280.



A. BAILY 8-POT CRUCIBLE LIFT-OUT FURNACE.



B. SMALL BAILY CRUCIBLE LIFT-OUT FURNACE USED FOR MELTING SILVER.

An incomplete log of one day's run is given. The power input averaged about 60 kw., being 22 kw. (120 volts, 190 amperes) at the start and rising to 86 kw. (120 volts, 720 amperes) as the resistor became heated. The voltage was then reduced from time to time as the furnace became hotter and the resistance of the resistor fell.

After two and one-half hours, in which nearly 150 kw. h. had been used, 25 pounds of copper was charged and was melted in 25 minutes, using about 28 kw. h. The power was kept on between heats. After 25 minutes, in which about 25 kw. h. was used, another 25 pounds of copper was charged and poured at 1,300° C. in 32 minutes, having used about 30 kw. h. The furnace was then heated empty for 1 hour and 15 minutes and a heat of nickel (weight not given) charged; this charge was poured 1 hour and 45 minutes later. Apparently but one of the melting holes is represented in the log. The furnace could not show its true efficiency under such a test, only 25 pounds of copper being charged in a furnace made to take two No. 50 crucibles. Seven and one-half hours and over 400 kw. h. were required to melt 50 pounds of copper and an unspecified weight of nickel.

The resistor developed hot spots, and the resistance of the coke resistor changed from day to day. Vickers says: "The furnace is not particularly efficient from a thermal standpoint and it is doubtful whether a granular-resistance furnace can be improved to any great extent. Some other form should be devised."

GREAVES-ETCHELLS CRUCIBLE FURNACE.

Greaves and Etchells⁶⁴ suggest a crucible lift-out furnace for three-phase current. In this furnace a granular resistor surrounds a refractory cylinder, within which a single crucible is set. Six electrodes, suitably connected to the different phases and separated by blocks of nonconducting material, so that a uniform flow of current in the resistor is produced, project downward into the annular ring of granular resistor. It is not known whether or not this furnace has been constructed.

BAILY CRUCIBLE LIFT-OUT FURNACE.

A small Baily furnace, made by the Electric Furnace Co., has been in commercial use in the melting of silver at the plant of W. A. Rogers, Ltd., Niagara Falls, since 1914. This furnace is a rectangular fire-brick box with two resistor troughs, connected in series, along the sides. (See Pl. I, *B*.) Two small crucibles are set on small fire-brick pedestals between the resistors. The furnace is rated at 40 kw. and is said to produce 1,000 ounces of silver per hour after the furnace is fully heated up, or eight heats (16 pots) in a

⁶⁴ Greaves, H. A., and Etchells, H., British Patent 115,866 of 1917.

10-hour day. According to Miller,⁶⁵ the power consumption is about 960 kw. h. per ton, and there are practically no metal losses.

FEATURES OF FURNACE.

In February and March, 1915, at the plant of the Detroit Copper and Brass Rolling Mills, Detroit, a Baily furnace was tested, which was the largest electric brass furnace built up to that time. (See Pl. I, A.) One of the writers was present during this test.

The primary current, which was single-phase alternating-current, 440-volt, 60-cycle, was led to a transformer having a series of oil switches for changing the transformer ratios. The transformer voltages were 242, 231, 220, 209, 198, 154, 143, 132, 121.

The furnace, which was rated at 200 kw., was set in an excavation, with its top a little above the floor level. A rectangular steel shell measuring approximately 10 by $8\frac{1}{2}$ by 6 feet and having suitable stiffening ribs inclosed the whole furnace.

The furnace floor was laid on two courses of hollow building tile, the spaces in which were filled with infusorial earth. On this were two $2\frac{1}{2}$ -inch courses of fire brick. The side walls were of 9-inch fire brick, backed by 6 inches of loose infusorial earth, and the end walls of $4\frac{1}{2}$ -inch fire brick, backed by 6 inches of loose infusorial earth. The straight side walls extended about $1\frac{3}{4}$ feet above the floor proper, and the roof was an arch 9 inches thick. In the bottom of the furnace were laid eight large fire-brick slabs about 4 inches thick, on which the crucibles were set.

The resistor troughs were rammed in place in wooden forms of carborundum fire sand and water glass, and the wooden forms were later burned out. The troughs were 9 by 6 by 94 inches, inside dimensions, and their walls were about 2 inches thick. They were supported at about 1-foot intervals by silica brick, by which the bottom of the trough was raised 5 or 6 inches from the floor in order to allow free radiation from the bottom of the resistor. A row of fire brick was laid at an angle across the joint between floor and side wall, near the lower edge of the resistor trough, to reflect the heat backward into the chamber. The arched roof, 9 inches thick, had its bottom $3\frac{1}{2}$ feet above the floor proper at the center of the span. Four oval holes in the roof about 15 inches wide by $2\frac{1}{2}$ feet long gave access to the crucibles. Aside from the resistor troughs and the silica brick supports for them the whole furnace lining was ordinary fire brick set in red clay.

The resistor walls were about 3 inches from the fire-brick side walls. The crucibles were placed about 4 inches from the resistor,

⁶⁵ Miller, D. D. The electric furnace for heating nonferrous metals: Jour. Am. Inst. Metals, vol. 11, 1917, p. 283.

about 12 inches from the end walls, and were 6 to 9 inches apart the short way of the furnace and 9 to 12 inches apart the long way.

The tops of the crucibles were about $1\frac{1}{2}$ feet from the bottom of the roof arch at the center of the span. The bottoms of the crucibles were about 4 feet below the upper steel shell of the furnace. The furnace bottom was built slightly sloping toward one end, and a tap hole, plugged by a brick, was provided with the idea of draining off spilled metal.

This furnace had a volume of 440 cubic feet in the walls, roof, and bottom, with a surface area of 390 square feet. The crucibles and contents occupied 10 cubic feet, and there was 60 cubic feet of vacant space in the furnace.

ELECTRODES.

The electrodes were 4 by 8 inch (made up of two 4 by 4 inch) carbon, extended at each end into the resistor troughs, and extended outside the furnace into asbestos millboard boxes in which was carborundum fire sand. Flexible copper strips were bolted to the electrodes and cable or busbars to the strips. There was no water cooling.

RESISTORS.

The resistors were each 99 inches long by 6 inches deep by 9 inches wide (dimensions inside trough), giving in series 188 inches of length and 54 square inches cross section. The highest voltage used was 242 at 205 kw.—a maximum of about $1\frac{1}{3}$ volts per inch length and $15\frac{1}{4}$ amperes per square inch of cross section. The resistor material was granular (chip) Acheson graphite of 3 to 6 mesh. It was heaped over the electrodes. The resistor was replenished when necessary through a long iron spout.

ROOFS AND COVERS.

The four oval openings in the roof were covered by four rectangular covers, about 17 inches wide by 30 inches long by 8 inches high, consisting of fire brick, topped by kieselguhr, all held in a five-sided steel box, with the open side down. These heavy covers were mounted on 6-inch car wheels running on five heavy I-beams placed across the furnace as tracks. The steel box projected downward about an inch below the bricks of the cover and fitted into a rectangular groove surrounding the oval opening, into which sand was placed to form a sand seal. By means of long handles and a system of toggle joints the cover could be lifted far enough to clear the roof, and an automatic catch, actuated by a spring, held the cover up so that it was free to roll on the wheels. When the cover was to be replaced, it was rolled into the proper position over the sand seal, and by

pulling a chain on the handle the catch was thrown out and the cover would drop into place. The handle could be thrown back out of the way in order to get into the furnace on the handle side of the cover. Each cover thus served one opening, or two crucibles, as it could be rolled either way.

CRUCIBLES.

The crucibles were No. 70's, of the same form and size as those used in coke furnaces of the plant. Like crucibles for crucible steel, they were more nearly cylindrical in form than are ordinary foundry crucibles. At first only the tongs used on coke furnaces were provided; the depth of the electric furnace, however, was so great that the workmen's hands were but a few inches above the furnace roof when using them, and longer tongs had to be used. As the roof openings were only about 15 inches the short way and the crucible plus the tongs had an equal width, the tongs to clear the openings had to be run across the furnace.

This furnace was designed to melt 1 ton of yellow brass with 500 kw. h. or less after temperature equilibrium was reached; that is, under continuous 24-hour operation.

PRELIMINARY DRYING AND HEATING OF FURNACE.

The power was first thrown on the new furnace at 4.30 p. m., February 19, 1915, the resistors being in multiple. The wooden form for the resistor troughs was slowly burned out and the empty furnace heated off and on at rather low power. At 3.08 p. m., February 24, the chamber was at 1,975° F. (1,080° C.), 4,110 kw. h. having been used in drying and heating the furnace.

Various attempts to melt were made in which numerous difficulties cropped up, the most serious of which was due to the presence of so many crucibles in one large inclosure. When a cover was opened to lift a pot the outrush of hot gas was so great as to make working over the furnace very hot and arduous.

Moreover, the furnace was full of zinc fume, which made it hard to see the location of the pot, so that it was difficult to place the tongs so as to avoid spilling the metal. Spilled metal, especially if it happened to drop into the resistor, caused even worse fume, and it was decided to add a flue to the furnace to take off the fumes.

After the flue was finished a test was made, first preheating the furnace chamber to 1,300° C.

The alloy to be melted was 58 per cent copper and 42 per cent zinc, this alloy having about the lowest melting temperature and the lowest pouring temperature, estimated at 1,025 to 1,050° C. (1,875 to 1,925° F.), of any used in the shop. The charges weighed 209.5

pounds each and consisted of 75 pounds scrap brass (usually heavy pieces), 75.5 pounds copper, and 59 pounds zinc.

The test was started at 8 a. m. March 2, when the first pot was charged. The eighth pot was charged at 8.37 a. m. The 242-volt tap was used till 8.15 a. m., when 185 kw. were being drawn. The 231-volt tap was then used till 8.45 a. m., when 192 kw. were being drawn. The 220-volt tap then was used till 9.08 a. m., when 168 kw. were being drawn, power dropping on this tap. The 231-volt tap then was used till 9.49 a. m., when 205 kw. were being drawn and a fuse blew. At 9.55 a. m. the fuse was replaced and power again put on, using the 220-volt tap, which gave 187 kw. At 10.07 a. m. the 198-volt tap was used and 145 kw. drawn. The power dropped on this tap to 143 kw. at 10.15 a. m. From 10.17 to 11.07 a. m. the power was thrown off during a wait for a new sledge for bending tongs into place; then the 231-volt tap was put on and 110 kw. drawn, which rose to 122 at 11.15 a. m. At 11.22 a. m. the power was thrown off, as it was decided not to charge any more metal till good double-prong tongs were available.

The resistor had burned away somewhat, which may partly account for the trouble in maintaining the desired power. On too high a tap the power would shoot up too much, and on too low a tap it would drop too much. The attempt in this test was to use as much power as the furnace would stand.

The temperature of the chamber dropped from $1,300^{\circ}$ to $1,200^{\circ}$ C. at 9.15 a. m., as the cold charges were put in, rose to $1,340^{\circ}$ C. at 10.15 a. m., fell when the power was off to $1,320^{\circ}$ C., then held about constant till 11.30 a. m., the power being off at 11.22 a. m. At 11.45 a. m. it had dropped to $1,305^{\circ}$ C. The pots in the furnace after 11.22 a. m. were taken out on stored heat, the last coming out at 12.50 p. m., when the temperature was $1,920^{\circ}$ F. ($1,050^{\circ}$ C.), the covers having been open to let fume escape. The covers were then opened a great deal to allow replacing the displaced bottom bricks and to replenish the resistor, and at 3.45 p. m. the temperature of the chamber was 815° C.

TROUBLES.

At 8.50 a. m. the caster burned his clothing from a flare of gas and fume over his feet and objected to the excessive heat. He declared the conditions were far worse for the melter than in handling crucible steel and could not be endured in summer.

The roof in the center of the furnace showed signs of settling, was red-hot to the steel shell, and the middle rail had warped so that one or two covers had to be moved by a bar, as they could no longer be rolled. Because the covers were warped the sand seal was no longer effective, and zinc fumes came out of the furnace even when all

covers were closed. The fumes were very bad after the first pots were speltered, and the new flue seemed to have no effect, possibly because the old annealing furnace, into which it opened, was not tight enough.

Much trouble developed with the tongs, partly because the single-prong tongs did not get a firm grip, but chiefly because the fumes made the pots invisible and the heat was hard even for gloved hands at several feet above the openings. No asbestos gloves were provided.

A still worse trouble was caused by the incipient slagging of the fire-brick blocks on which the crucible rested, so that the crucibles adhered to the blocks. Even if the tongs were placed properly, the crucible could not be pried loose. Sometimes the bottom blocks came up and had to be barred loose from the hanging crucible, a dangerous proceeding with tongs softened by heat; sometimes one man placed the tongs, fastened them tightly, and forced them from side to side, while another took hold of the crucible top with a long pair of speltering tongs and did the same. After many attempts—in the case of two crucibles, seven each—the pots were lifted, but the bottom blocks were so much disarranged that the crucibles could not be replaced. Three crucibles were ruined by breaking pieces out of the top and by scoring with crucible tongs. In efforts to dislodge the crucibles much metal was spilled, and much ran out when the tongs broke pieces out of the top of the crucibles. All this spilled metal caused heavy fume, and as the tong trouble caused delay several pots became overheated, adding to the fume.

Carborundum fire sand was then placed under each crucible to prevent sticking.

On account of the delays through crucibles sticking to the bottom this run did not go one full round of eight pots before it was necessary to throw off the power. Consequently the figures of power consumption again are only approximate. They approach 500 kw. h. per ton under conditions of continuous operation. On account of the spilling into the furnace, the figures for weight of metal lost would have been of no value and were not taken.

At 3.45 p. m., after the bottom bricks were replaced and carborundum fire-sand was put under all crucibles to prevent sticking, when the temperature was 815° C., power was turned on again to heat the furnace for the following day's run. At 7.40 a. m. the next morning, March 3, the temperature was 1330° C. About 1,500 kw. h. were used in 16 hours in heating the empty furnace.

A new pair of long double-prong tongs was made, so that the crucible could be grasped more securely. Another full-capacity test was then run.

SECOND FULL-CAPACITY TEST.

• The test started at 7.40 a. m. On 242 volts the power was 168 kw., and crept up to 192 kw. at 8.02 a. m., when the 231-volt tap was used; the power then started at 183 kw. and reached 195 kw. at 8.30 a. m.; the 220-volt tap then gave 174 kw., but the power fell on this voltage to 156 kw. at 9.30 a. m. As the temperature was still as high as the refractories would stand, a lower tap (198 volts) was thrown in, and the power fell from 135 kw. to 101 kw. at 10.30, when the 220-volt tap was again used, the furnace taking 132 kw.

The temperature in the chamber fell, as cold metal was charged, from $1,330^{\circ}$ C. at 7.40 a. m. to $1,230^{\circ}$ C. at 8.30 a. m., and then rose to $1,345^{\circ}$ C. at 9.45, falling to $1,205^{\circ}$ C. at 10.30 and rising to $1,275^{\circ}$ C. at 10.58 a. m. The temperature near the resistor was not so much affected by charging and rose from $1,355^{\circ}$ C. at 7.40 a. m. to $1,445^{\circ}$ C. at 10.00 a. m., and then fell to $1,405^{\circ}$ C. at 10.58 a. m.

ADDITIONAL TROUBLES.

The condition of the roof, covers, and warped rail in the middle of the furnace became worse during this run. Some bricks from one of the end covers fell into one pot of metal. The pots did not stick to the bottom bricks, and the new tongs worked well as long as the caster could see where to place them. The first five pots came out on the first attempt to lift them, a record far better than in the previous tests.

The working conditions were still bad. The third pot to be recharged and put back in the furnace was not set in exactly the proper position, as the fumes made it impossible to see what was being done. The bottom was not replaced exactly level after being torn up by the sticking of the pots on the previous day. The pot had been charged with all the scrap brass and small pieces of copper it would hold before being replaced in the furnace, as this was easier on the men than replacing the empty crucible and then charging it. On the first heat in any one pot, as the empty crucibles had remained in the furnace, a long funnel was used for charging.

This third pot tipped over and some of its contents were spilled, but it was righted without much trouble.

At 10.58 a. m. the fumes were very bad, the flue having no appreciable effect; it was impossible to see into the furnace, so that the tongs were not properly placed on one pot. In consequence this pot dropped from the tongs, spilling about half its contents. This hot metal, almost at its boiling point, spilled into a resistor trough, exploded because of the sudden volatilization of zinc, and a shower of molten metal burned the clothes of the bystanders. The granular resistor was blown out of the trough, and the fume from the spilled metal was so great that the test had to stop at once. As before, the metal in pots already in was melted by stored heat.

The difference in temperature between the end of the chamber and the side by the resistor began to equalize fairly soon after the power was turned off, as is shown below :

TABLE 3.—*Equalization of temperature between end of chamber and side of resistor.*

Time.	Temperature of chamber, no power on.		Temperature of wall near resistor.		Difference.
	° F.	° C.	° F.	° C.	
10.58 a. m.	2,330	1,275	2,560	1,405	130
11.30 a. m.	2,300	1,260	2,500	1,370	110
12.00 m.	2,260	1,240	2,420	1,330	90
12.30 p. m.	2,225	1,220	2,320	1,270	50
1.00 p. m.	2,170	1,190	2,265	1,240	50
a 1.24 p. m.	2,130	1,165	2,210	1,210	45

a Last pot out.

TABLE 4.—*Log of final test of Bailly 8-pot furnace, March 3, 1915; 58 per cent copper, 42 per cent zinc.*

Con-secutive heat No.	Pot No.	Time started charging.	Time all charge in but zinc.	Time zinc added.	Time pulled.	Remarks.
27	1	7.40 a. m.	8.39 a. m.	9.09 a. m.	9.21 a. m.	Pot not charged. Do. Do.
28	2	7.44 a. m.	8.40 a. m.	9.12 a. m.	9.35 a. m.	
29	3	7.48 a. m.	8.45 a. m.	9.15 a. m.	9.56 a. m.	
30	4	7.52 a. m.	8.46 a. m.	9.17 a. m.	10.08 a. m.	
31	5	8.10 a. m.	8.37 a. m.	a 11.42 a. m.	a 12.02 p. m.	
32	6	8.05 a. m.	8.49 a. m.	a 11.35 a. m.	a 11.51 a. m.	
33	7	8.02 a. m.	8.48 a. m.	10.29 a. m.	a 11.32 a. m.	
34	8	7.58 a. m.	8.47 a. m.	10.26 a. m.	10.32 a. m.	
35	1	9.30 a. m.	10.11 a. m.	a 12.29 p. m.	a 12.35 p. m.	
36	2	9.47 a. m.	10.13 a. m.	a 12.31 p. m.	a 12.45 p. m.	
37	3	10.05 a. m.	10.35 a. m.	a 12.54 p. m.	a 1.03 p. m.	
38	4	10.25 a. m.	10.45 a. m.	a 12.57 p. m.	a 1.14 p. m.	
39	8	10.47 a. m.	a 11.40 a. m.	a 1.20 p. m.	a 1.24 p. m.	

a No power on; melting done by stored heat.

Between 7.40 a. m. and 10.54 a. m., or in about three and one-fourth hours, nearly 525 kw. h. had been used, or the average power input was a little over 160 kw. The final temperature at 10.54 a. m. was 55° C. lower in the chamber and 50° C. higher near the resistor at the end than at the start; that is, the furnace temperature may be taken as the same at the start and finish. The work completed in this period was as follows:

Work done in heat.

	Full heats.
5 pots out, equivalent to	5.0
4 pots all in but spelter, but not ready to spelter, approximately half done	2.0
1 pot ready to come out	1.0
2 pots ready to spelter, approximately 80 per cent done	1.6
1 pot just in, approximately 10 per cent done	.1
Total full heats	9.7

If these 9.7 full heats be taken as equivalent to 10 full heats (2,095 pounds) for truly continuous running, the power consumption was 500 kw. h. per ton.

During the whole test, from the first warming up of the furnace to the time the power was shut off, over 12,500 kw. h. were used, and about 4 tons of metal melted.

The crucibles seemed to be in fairly good condition at the end of the test, considering that they had been left empty continuously in the furnace during all heating and cooling periods and had been severely damaged by the first two sets of tongs.

METAL LOSS.

Disregarding the spilled pot, the 12 charges, 2,514 pounds (clean metal), melted in the last test gave 2,370 pounds of metal in ingots, a gross loss of 144 pounds, or 5.75 per cent. Ninety pounds of metal was recovered from spillings and skimmings, making the net loss 54 pounds, or 2.15 per cent. The furnace as built was a failure mainly for the following reasons:

1. Fume and heat made conditions extremely bad for the workmen. Nearly everyone working around the furnace had "brass shakes."

2. The rate of production was low.

3. The power efficiency was not good.

4. The furnace took so long to cool and to heat in case of needed repairs that an accident interfered greatly with production.

GIROD FURNACE.

Girod⁶⁶ suggested a crucible furnace with a number of crucibles contained in an inclosure, on the sides and bottom of which is a granular resistor. No data on its actual use or trial have come to light. As the design involves driving the heat through the walls of the inclosure as well as through the crucibles, it seems to be of low efficiency and to involve many difficulties in the maintenance.

SNYDER CRUCIBLE LIFT-OUT FURNACE.

The Commonwealth Edison Co., of Chicago, desiring to aid the development of electric furnaces, in order to lay the foundation for the sale of power for them, had a furnace designed by F. T. Snyder and tested at the plant of the L. Wolff Manufacturing Co., Chicago, in 1913 and 1914. The later tests were made by H. M. St. John.

This was a pit furnace, taking one No. 80 crucible. The resistor was a cylinder made of ordinary crucible material (graphite bonded with fire clay). Slots were cut in this cylinder and filled up with

⁶⁶ Girod, P., U. S. Patent 885,745, Apr. 28, 1908; application Dec. 20, 1905.

alundum cement, the object being to insure stability, and thus to increase the resistance of the resistor. The crucible was set inside the resistor, which, in turn, was surrounded by fire brick and heat-insulating brick walls. Electrical control was obtained by varying the voltage.

Some yellow brass was melted in this furnace, but despite many attempts to improve it the life of the resistors was short—not over 40 hours running time, even though for half of that time the resistor temperature was below $1,000^{\circ}\text{C}$. The resistor could not be run at a temperature, of the resistor itself, above $1,300^{\circ}\text{C}$; no efficient brass melting could be done in a furnace whose resistor temperature is not over $1,300^{\circ}\text{C}$. for reasons clearly pointed out by Northrup.⁶⁷ The short life of the resistor was due both to oxidation of the resistor, which was retarded somewhat by arranging a slow drip of oil into the furnace, and to the development of hot spots in the resistor and consequent melting of the fire-clay bond.

Whenever attempts were made to melt brass at a commercial rate of speed, the resistor broke down before reliable results could be obtained. The incomplete data indicated that even if the resistor troubles could be overcome, a furnace of such a type and size could hardly be expected to reach as low a figure as 500 kw. h. per ton of yellow brass, even under the most favorable conditions.

GREENWOOD AND HUTTON CRUCIBLE LIFT-OUT FURNACE.

Greenwood and Hutton⁶⁸ describe a furnace in which a crucible is set inside a cylindrical grid made up of carbon rods standing vertically, their ends so joined by carbon blocks that the rods are connected in series. (See figs. 2 and 3.) The rods are covered with a carborundum fire-sand—water glass coating to prevent oxidation. The furnace handled a 90-pound charge and took about 20 kilowatts at about 65 volts, 300 amperes. Data are given only on two heats of 90 pounds of “nickel-silver” (nickel brass or German silver) scrap. In these, starting from a cold furnace, the first heat came out in 3 hours, using 54 kw. h., the second in 1 hour and 35 minutes, using 29 kw. h. The authors calculate that on 10-hour operation the furnace would melt nickel brass with about 750 kw. h. per ton, and on 24-hour operation at about 600 kw. h. per ton. These figures would be somewhat reduced for alloys of lower melting points than nickel silver.

No data are given to indicate the probable life of the resistor, but the resistor is inherently fragile, subject to weakening by oxida-

⁶⁷ Northrup, E. F., *Production of high temperature and its measurement: Met. and Chem. Eng.*, vol. 17, 1917, p. 685.

⁶⁸ Greenwood, H. C., and Hutton, R. S., *Note on an electric-resistance furnace for melting in crucibles: Jour. Inst. Metals (British)*, vol. 17, 1917, p. 239.

tion, and because of the careful fitting of joints required in construction expensive in comparison with its probable life.

HOSKINS CRUCIBLE LIFT-OUT FURNACE.

A more fully developed crucible furnace is the Hoskins carbon-plate resistor furnace, which has been commercially used in small

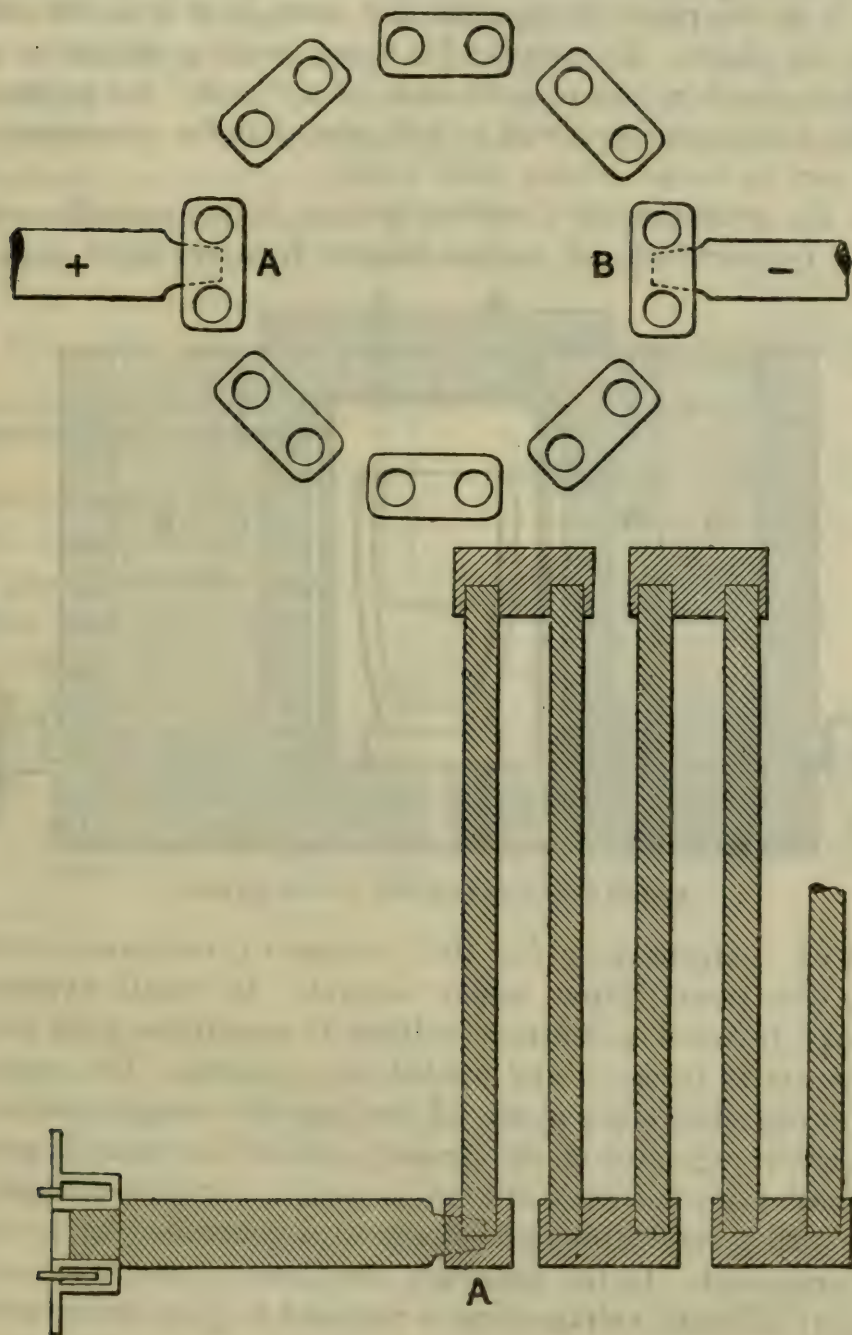


FIGURE 2.—Detail of Greenwood and Hutton resistor.

sizes by the Hoskins Manufacturing Co., of Detroit, in the production of nickel-chromium alloys. As the need for larger melting units has increased, the crucible furnace has been gradually supplanted for this purpose by the ordinary or horizontal ring type of

induction furnace, and the indications are that the latter type in turn will be displaced by direct-arc furnaces for melting these alloys.

The crucible furnace has a resistor composed of thin carbon plates, usually $\frac{1}{4}$ inch thick, $1\frac{3}{4}$ to $2\frac{1}{4}$ inches wide, and 8 to 15 inches high, in various sizes of furnaces. The plates are set upright and against each other, like the leaves of a book. Part of the resistance of this resistor is in the plates themselves, but most of it is in the contacts between the plates. By means of a screw bearing against a carbon or graphite block at one or both ends of a "book" the pressure between the blades can be varied at will, and thus the resistance of the resistor can be varied within wide limits.

Since the resistance of a carbon resistor falls markedly with increase of temperature, all carbon-resistor furnaces must have some

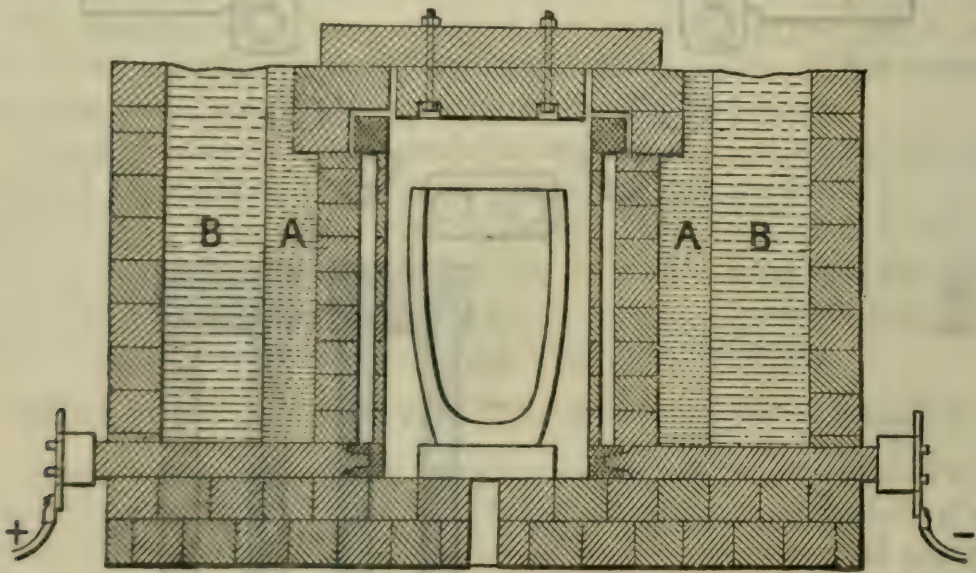


FIGURE 3.—Greenwood and Hutton furnace.

method of compensating for this change of resistance, and thus keeping the power input under control. In small experimental laboratory furnaces a constant voltage is sometimes used and part of the power is absorbed and wasted in a rheostat. For commercial use, however, some other means of varying the voltage must be used. An induction regulator on the primary side of the transformer gives some regulation, but even if that is used a variable-voltage transformer with several different voltage taps controlled by switches is usually required. If the induction regulator is not used, a larger number of different voltage taps is required to give real control over the furnace.

With the Hoskins furnace a considerable control of power input can be effected by altering the contact resistance between the plates, so that a transformer with fewer voltage steps and with longer steps can be used.

In the early days of the work of the Bureau of Mines, before experience had shown that electric crucible lift-out furnaces for brass were not likely to be of commercial use, the Hoskins type was tried out in several different forms and sizes, the first object being to determine the metal losses of different alloys in a crucible lift-out furnace. The patent⁶⁹ on this type of furnace is controlled by the Hoskins Manufacturing Co., but through the courtesy of Mr. A. L. Marsh of that firm the bureau was permitted to utilize the principle of the furnace in the construction of experimental furnaces for laboratory tests. In a later patent Thomson⁷⁰ also shows a crucible lift-out furnace surrounded by an adjustable carbon resistor, whose resistance lies mainly in the contacts between the carbon pieces.

**BUREAU OF MINES TESTS OF
HOSKINS-TYPE FURNACE.**

A good many tests of the Hoskins furnaces were made which gave instructive data on metal losses and on furnace design. The original data of these tests, as well as much other early data, were lost in the fire that destroyed part of Morse Hall, Cornell University, in February, 1916. The entire contents of the Ithaca field office were lost in the fire,

so that the data below are taken from summarized reports that had been made to the Washington office.

Most of the small Hoskins furnaces made by the Hoskins Manufacturing Co. have two rows of carbon plates on two sides of the furnace, connected by a heavy carbon or graphite plate at the back, heat thus being generated on two sides only. (See fig. 4.) Most of the furnaces built by the bureau had resistor plates completely surrounding the crucible. In five of the modifications tested, the furnace took but one crucible, and in one modification three No. 20 crucibles were used. Carborundum bricks usually supported the blades, with magnesite brick next the carbon plates, though, of course, not in contact with them. Back of the magnesite were fire

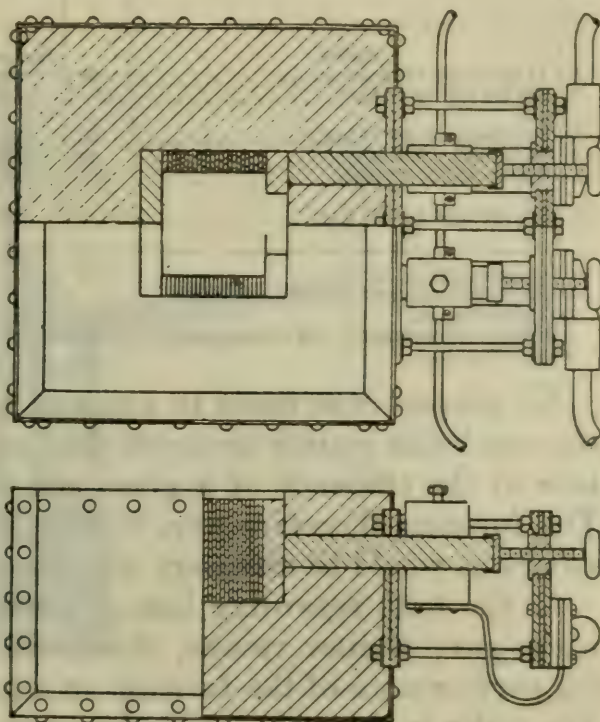


FIGURE 4.—Diagram of Hoskins crucible lift-out furnace.

⁶⁹ Marsh, A. L., U. S. Patent 882,788, June 5, 1906.

⁷⁰ Thomson, J., U. S. Patent 950,879, March 1, 1910 (see fig. 7).

brick, and on the outside either loose infusorial earth in a sheet-iron shell or infusorial-earth brick. Fire-brick covers fitting into a sand seal and provided with charging holes closed by smaller fire-brick covers were used. Table 5 shows some of the general dimensions of the furnaces.

TABLE 5.—Dimensions of Hoskins small-sized crucible lift-out furnaces.

No.	Dimensions of melting chamber (inside plates).	Crucible.				Height of carbon plates.	Location of bottom of crucible in relation to bottom of resistor.	Kw. rating.
		No.	Height.	Largest diameter.	Capacity, brass.			
	<i>Inches.</i>		<i>Inches.</i>	<i>Inches.</i>	<i>Pounds.</i>	<i>Inches.</i>		
1	11 by 11 by 14 $\frac{1}{2}$ high.....	20	10 $\frac{1}{2}$	8 $\frac{1}{2}$	60	8	Level.....	50
2	11 $\frac{1}{2}$ by 11 $\frac{1}{2}$ by 17 high.....	(a)	10 $\frac{1}{2}$	9	90	8	2 $\frac{1}{2}$ inches above.	50
3	10 $\frac{1}{2}$ diameter by 18 high.....	20	10 $\frac{1}{2}$	8 $\frac{1}{2}$	60	8	Level.....	50
4	13 $\frac{1}{2}$ by 13 $\frac{1}{2}$ by 19 high.....	40	12 $\frac{1}{2}$	10 $\frac{1}{2}$	120	10	do.....	75
5	12 $\frac{1}{2}$ by 12 $\frac{1}{2}$ by 23 high.....	(b)	16	9	145	15	1 inch below.	65
c 6	10 $\frac{1}{2}$ by 10 $\frac{1}{2}$ d by 13 $\frac{1}{2}$ high.....	20	10 $\frac{1}{2}$	8 $\frac{1}{2}$	e 60	8	Level...	50

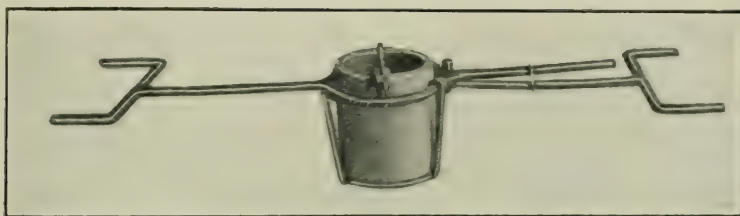
a Special short cylinder.
b Special tall cylinder.
c Triple furnaces.
d Middle compartment; end compartments straight next to middle, oval toward ends.
e Each crucible.

No attempt was made to run any of these furrows continuously, the aim being mainly to secure data on melting losses and a general idea of the efficiency of a given size and type in the use of power. The furnaces therefore were built as cheaply as possible and not as solidly as would be necessary were they intended for commercial use.

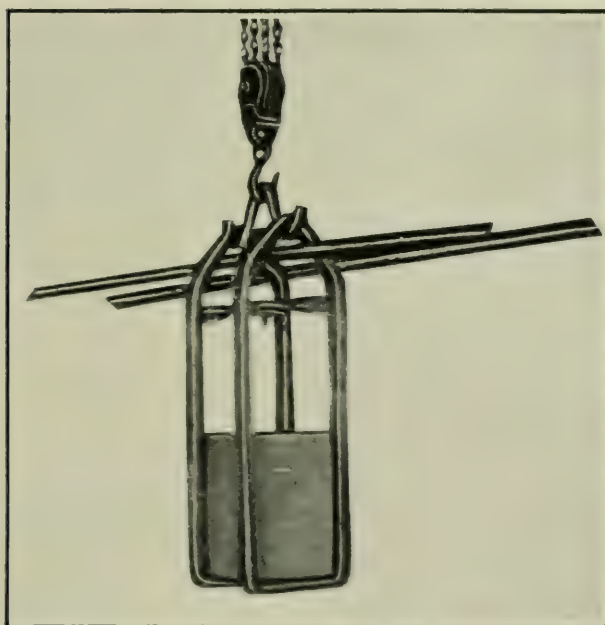
As the tests regarding loss of metal on the various sizes of furnaces gave similar results, these will be considered together after the performance of the furnaces in other respects has been discussed. The order in the table is not always that in which the furnaces were tested.

The results on furnaces 1, 2, and 3 may be considered together. Furnaces 1 and 2 were almost identical, having a square melting chamber, with resistor plates on all four sides, square 2 by 2 inch graphite end blocks as tall as the plates at three corners, each with two adjusting screws bearing on two carborundum bricks set back of the blocks for varying the pressure on the blocks. Graphite electrodes brought to the ends of the rows of resistor plates were installed at the remaining corner and insulated from each other by a magnesite brick.

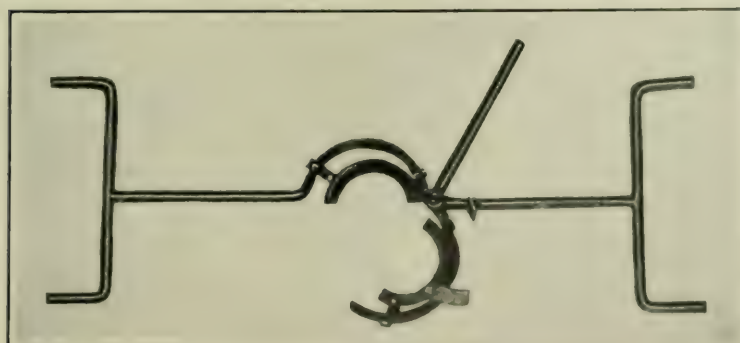
Furnace 1 used the standard crucible, handled by the usual tongs. The shape of such a crucible leaves some waste space in the melting chamber, and a cylindrical crucible was tried in furnace 2 to test the advantage of utilizing this waste space. Special means had to be provided for lifting the cylindrical crucible, as it had no bilge.



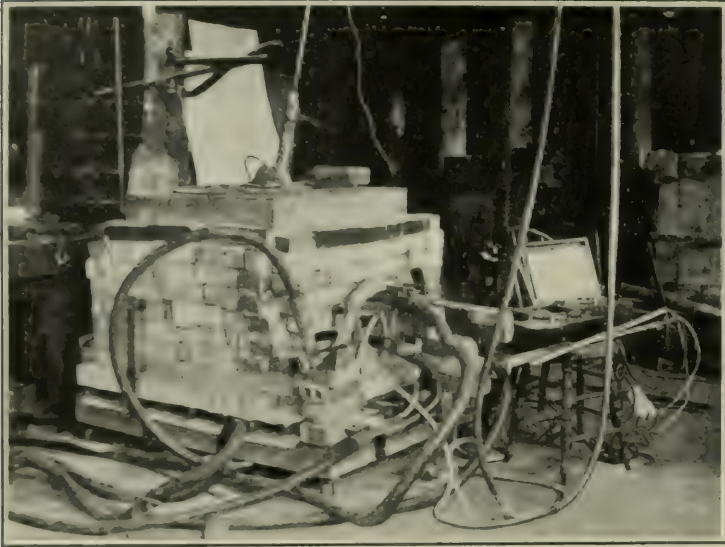
A. SHANK FOR CYLINDRICAL CRUCIBLE.



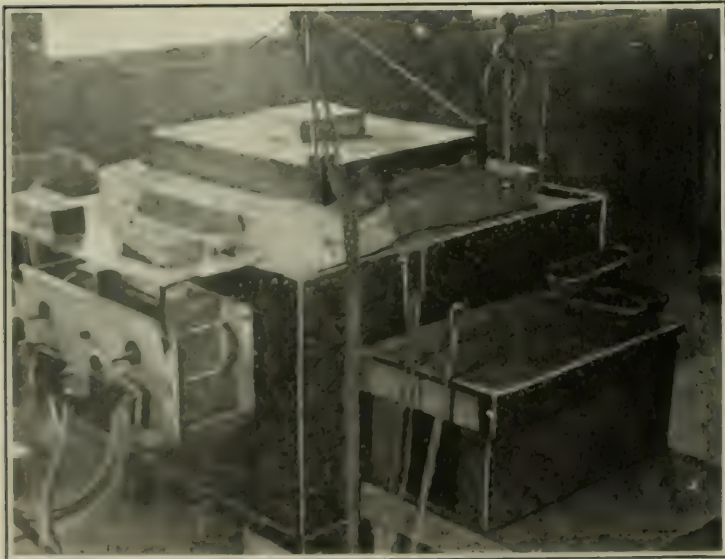
B. LIFTING DEVICE FOR CYLINDRICAL CRUCIBLE.



C. ANOTHER SHANK FOR CYLINDRICAL CRUCIBLE.



4. EXPERIMENTAL HOSKINS-TYPE CRUCIBLE LIFT-OUT FURNACE FOR NO. 40 CRUCIBLE.



7. HOSKINS CRUCIBLE LIFT-OUT FURNACE FOR NO. 70 CRUCIBLE.

This was accomplished by a pair of loop tongs. The crucible was set on a brick in the furnace, and when it was ready for pouring one loop was lowered into the furnace and slipped under one side of the crucible. The other loop was then similarly inserted and a pin, extending downward on a V-shaped projection extending from the upper part of the loop, was inserted into a hole on a similar V-shaped projection on the other loop. A VV-shaped bar held the two loops in the two outer curves and was hoisted by a hook in the center loop. The crucible was held securely as it was hoisted from the furnace. It was then set down upon a round fire block, the loop tongs removed, and a basket shank slipped about the crucible for pouring. The lifting and pouring devices are more thoroughly described by Lohr⁷¹ and are shown in Plate II, *A, B, C*.

Furnace 3 was built to get away from the waste space in the corners of the furnaces with square melting chambers. In this the resistor was made as near to a circle as possible by making it in the form of a hexagon, five sides of which were made up of rows of carbon plates pressing against two sides of an equilateral-triangular prism of graphite. The adjusting screw bore against a carborundum brick back of the third side of the triangle. The electrodes, with magnesite brick insulation between them, were on the sixth side of the hexagon.

In order to life the crucible, which was too close to the resistor to allow the use of any sort of tongs, it was set on a tall brick pedestal that could be raised by a handwheel and gearing till the bottom of the crucible was above the resistor blades, when the crucible could be grasped by tongs or could be lowered until the bottom of the crucible was on a level with the bottom of the resistor.

Representative runs on five furnaces, all melting an alloy of about 78½ per cent copper, 16 per cent zinc, 2½ per cent tin, and 3 per cent lead, charged in small ingots of 8 to 12 pounds, are tabulated in Table 6.

All furnaces were cold at the start save No. 4, which was at 375° at the start, and No. 5, which was at 350° C. The metal was poured at about 1,200° C., save with furnace 5, from which it was poured at about 1,165° C. A number of other runs were made with the furnaces, which agreed very well with those given below in Table 6.

⁷¹ Lohr, J. M., U. S. Patents 1,173,444 and 1,173,445, Feb. 29, 1916 (dedicated to the public).

TABLE 6.—Results of tests of different types of Hoskins furnaces.

Furnace 1. Square melting chamber; regular No. 20 crucible.

Heat No.	Power on.	Power off.	Weight of charge.	Power used. ^a
			Pounds.	Kw. h.
1.....	8.00 a. m. . . .	9.55 a. m. . . .	55	104.5
2.....	10.07 a. m. . . .	10.55 a. m. . . .	55	47
3.....	11.07 a. m. . . .	11.47 a. m. . . .	55	39
4.....	1.03 p. m.	1.37 p. m.	55	32.5
5.....	1.49 p. m.	2.27 p. m.	55	33
6.....	2.40 p. m.	3.13 p. m.	55	34.5
7.....	3.23 p. m.	3.53 p. m.	55	26.5
8.....	4.03 p. m.	4.30 p. m.	55	28.5
Total.....			b 440	c 345.5

Furnace 2. Square melting chamber; short cylindrical crucible.

			Pounds.	Kw. h.
1.....	8.00 a. m. . . .	9.35 a. m. . . .	85	86
2.....	9.45 a. m. . . .	10.26 a. m. . . .	90	37
3.....	10.37 a. m. . . .	11.18 a. m. . . .	90	31
4.....	12.30 p. m. . . .	1.18 p. m. . . .	90	32
5.....	1.28 p. m.	2.13 p. m.	90	29
6.....	2.24 p. m.	3.10 p. m.	90	28.5
7.....	3.20 p. m.	4.05 p. m.	90	28
Total.....			625	d 271.5

Furnace 3. Hexagonal melting chamber; regular No. 20 crucible.

			Pounds.	Kw. h.
1.....	8.00 a. m. . . .	9.38 a. m. . . .	55	73.5
2.....	9.49 a. m. . . .	10.26 a. m. . . .	55	36
3.....	10.36 a. m. . . .	11.16 a. m. . . .	55	32
4.....	12.27 p. m. . . .	1.10 p. m. . . .	55	30
5.....	1.20 p. m.	1.56 p. m.	55	28
6.....	2.08 p. m.	2.46 p. m.	55	26
7.....	2.56 p. m.	3.30 p. m.	55	26.5
8.....	3.40 p. m.	4.15 p. m.	55	25.5
Total.....			440	e 277.5

Furnace 4. Square melting chamber; regular No. 40 crucible (warm at start).

			Pounds.	Kw. h.
1.....	8.00 a. m. . . .	9.41 a. m. . . .	120	120
2.....	10.05 a. m. . . .	10.42 a. m. . . .	120	61
3.....	10.58 a. m. . . .	11.47 a. m. . . .	125	46
4.....	1.00 p. m.	1.41 p. m.	120	43
5.....	1.57 p. m.	2.43 p. m.	120	44
6.....	2.55 p. m.	3.35 p. m.	120	40
7.....	3.45 p. m.	4.28 p. m.	120	36
Total.....			845	f 390

Furnace 5. Furnace chamber at 350° C. at start; metal poured at 1,165° C., average.

			Pounds.	Kw. h.
1.....	7.00 a. m. . . .	8.55 a. m. . . .	147.5	132
2.....	9.17 a. m. . . .	10.30 a. m. . . .	146	60
3.....	10.50 a. m. . . .	11.43 a. m. . . .	140	45
4.....	11.59 a. m. . . .	12.46 p. m. . . .	140	49
5.....	1.12 p. m.	2.20 p. m.	138	32
6.....	2.35 p. m.	3.28 p. m.	138.5	30
Total.....			850	g 438

^a All kw. h. figures taken on secondary side of transformer.^b 16 per cent zinc alloy.^c Average, 7.7 kw. h. per 100 pounds.^d Average, 44 kw. h. per 100 pounds.^e Average, 63 kw. h. per 100 pounds.^f Metal charged at 12.01; no power on furnace over noon hour.^g Average, 46 kw. h. per 100 pounds.^h Part of heat 5 charged at 1.03 and left in furnace; no power on over noon hour.ⁱ Average, 41 kw. h. per 100 pounds.

In Furnace 5 a tall cylindrical crucible holding about 145 pounds of metal was used, the crucible being 16 inches tall, the resistor blades being 15 inches tall, with their tops level with the top of the crucible, the crucible bottom being thus 1 inch below the bottom of the resistor.

The crucible was split at the top in pulling heat 6 from the furnace, so the run could not be finished. Had two more heats been taken out, the power consumption would have been cut down to about $37\frac{1}{2}$ kw. h. per 100 pounds. The space available for pouring was so small and cramped that it was impossible to pour quickly and the time taken for pouring was excessive.

Much trouble was experienced in running furnace 5 on account of top heating. The top of the resistor blades were on a level with the top of the crucible and were 1 inch shorter than the crucible. The crucible was filled quite full on the first heats, and a good deal of heating was done by heat reflected by the roof. Melting took place first on top of the charge—not from the bottom as in the other furnaces where the resistor plates were at least 2 inches from the top of the crucible—and the bottom of the resistor was level with the bottom of the crucible ($2\frac{1}{2}$ inches below it in furnace 2). The metal on top was bubbling and spitting at the end of the heats, and although the pots were stirred the last metal poured was rather cold. The average pouring temperature was $1,165^{\circ}$ instead of $1,200^{\circ}$ C., as in the runs with the other furnaces.

In order to avoid trouble from overheating at the surface, it was necessary to reduce the power input below the figure desired in order to let conduction of heat through the metal keep pace with the rise in temperature and bring the metal out more evenly heated from top to bottom.

This test showed the desirability of heating crucibles from the bottom rather than from the top and indicated that surface overheating is likely to occur in hearth-type furnaces with deep baths heated from above unless some means of stirring the metal is adopted.

The boiling and spitting of the surface layer of metal was probably made more noticeable by the rather low barometric pressure (73.6 cm.) on the day of the test. For a crucible of this tall and narrow form to be useful it should be heated from the bottom, in order to set up thermal circulation by the rising of hotter metal, instead of being heated from the top and allowing the hotter metal to remain at the top. On regular operation these furnaces would give results about as follows, if they started on an eight-hour operation with the furnace at a temperature of 500° C. or more from the previous day's heating:

68723°—22—5

TABLE 7.—Summary of the probable performance of different sizes of Hoskins-type furnaces.

Furnace No.	Charge.	Kw. h. per ton.		Daily output.	
		8-hour operation.	24-hour operation.	8-hour operation.	24-hour operation.
	Pounds.			Pounds.	Pounds.
1.....	55	1,500	1,000	450	1,800
2.....	90	850	625	650	2,300
3.....	55	1,250	950	450	1,900
4.....	120	850	625	850	3,200
5.....	140	700	500	1,000	3,600

Besides the improvement in Nos. 4 and 5 over No. 1, which was to be expected, as the capacity of the furnace per charge was more than doubled, No. 3, in which the waste space between crucible and resistor was less than in No. 1, gives materially better results than No. 1; No. 2, in which the use of the short cylindrical crucible increases the capacity of the furnace over No. 1, is still more of an improvement over No. 1 and does as well in power consumption, though not in output, as No. 4. No. 5 did not show as much improvement as was expected because of the trouble from top heating.

Furnace 4, which is shown in Plate III, A, gave the results in Table 8 on yellow brass of 63 per cent copper, 33½ per cent zinc, 3½ per cent lead, charged as 10-pound ingots and poured at about 1,065° C.

TABLE 8.—Test on Hoskins furnace 4 for melting yellow brass; No. 40 crucible square furnace.

Heat No.	Power on.	Power off.	Pounds charged.	Kw. h.
1.....	6.40 a. m.	a 7.10 a. m.	125	114
2.....	7.36 a. m.	9.00 a. m.		
3.....	9.15 a. m.	10.11 a. m.	123	55
4.....	10.28 a. m.	11.17 a. m.	124	38
5.....	11.30 a. m.	12.10 p. m.	126	29
6.....	12.27 p. m.	b 1.10 p. m.	124	31
7.....	2.26 p. m.	3.08 p. m.	125	29.5
8.....	3.21 p. m.	4.20 p. m.	123	30
9.....	4.32 p. m.	5.29 p. m.	124	32
Total.....			994	c 358.5

a Power off 26 minutes, fuse blown.

b Part of charge for heat 6 put in at 1.29 p. m.

c Average, 36, kw. h. per 100 pounds.

On 10-hour operation on yellow brass and on calculated 24-hour operation furnace 4 should then give the following results: Charge, 125 pounds; kw. h. per ton, 10-hour operation, 700; 24-hour operation, 500; output, 10-hour operation, 1,000 pounds; 24-hour operation, 3,600 pounds.

Furnace 4 (single No. 40 crucible) used 181 carbon plates 2 by 10 by ¼ inch. The cold furnace started at about 200 volts, 150 amperes

(30 kilowatts); at higher power inputs the voltage and amperage were as follows at various times:

TABLE 9.—*Electrical data on Hoskins furnace 4.*

Kw.	Volts.	Amperes.	Kw.	Volts.	Amperes.
79	101	780	60	115	520
78	104	750	18	90	c 200
50	150	a 450	66	94	700
50	100	b 500	60	100	600

a Starting up after cooling at noon.
b At full running temperature.

c Reducing power at end of run.

The current taken at any voltage can be carried through a rather wide range by changing the pressure on the plates by means of the adjusting screws.

TRIPLE FURNACE.

In a furnace taking a single crucible the heat from half of the resistor only is directed toward the crucible. It seemed likely therefore that a gain in efficiency could be made if the resistors were placed between the crucibles, so that the heat from both sides of the resistor struck the crucibles directly. Moreover, if three separate square furnaces were made into one holding three crucibles the latter could readily be constructed with about only two-thirds as much area in its surface as the total area of the surfaces of the three separate furnaces.

This design is more fully described by Lohr and Gillett,⁷² who show also how it is adapted for three-phase current.

FURNACE 6.

A triple furnace for No. 20 crucibles (regular form) was constructed, in which there were but two rows of resistor plates, connected in series by a back plate, like the usual Hoskins design. Instead of the straight side walls next the resistors of a furnace for a single-phase crucible, the furnace was extended lengthwise, space being made outside each resistor for another crucible. The ends of the furnace were in semicircular form, the end walls being brought

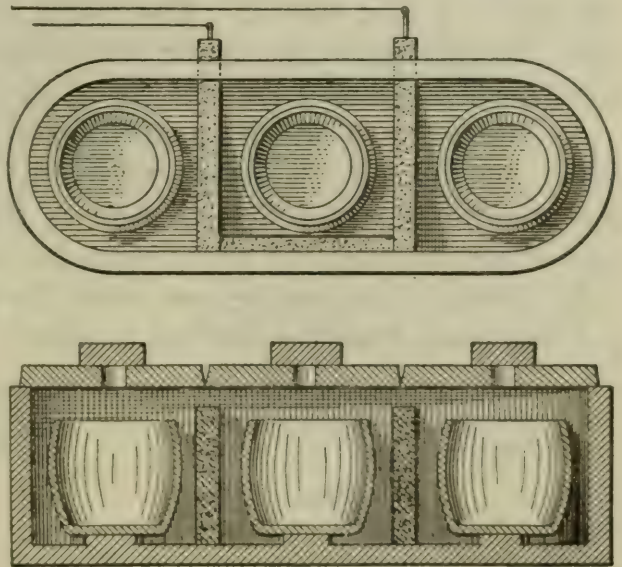


FIGURE 5.—Bureau of Mines crucible furnace, triple form.

⁷² Lohr, J. M., and Gillett, H. W., U. S. Patents 1,162,178 and 1,162,179 (dedicated to the public), Nov. 30, 1915.

as close to the outer crucibles as possible allowing room for tongs. The general principle of this furnace is shown in figure 5.

In the first construction the resistor plates were bare and not protected by troughs. As there were only two rows of resistor plates against the three rows in furnace 1, the resistance of the whole resistor was less, and it was desirable to run the furnace with as high a contact resistance between plates as possible; that is, with the plates as loose as possible. As the space allowed for the tongs was small in order to avoid waste, it was difficult to avoid hitting the plates when removing the crucibles. This tended to displace the plates. Hence the furnace was rebuilt, with the resistors inside carborundum troughs made up of slabs $\frac{1}{2}$ inch thick of pure unbonded carborundum, Refrax grade. Carborundum-slab covers were put over the troughs to protect the resistors from mechanical damage and from oxidation. The furnace cover was made in three portions, each having a charging hole, so that but one section had to be removed to take out any one crucible.

The data on a run melting the regular alloy used in comparing the different furnaces—78½ per cent copper, 16 per cent zinc, 2½ per cent tin, 3 per cent lead—follow:

The furnace was at 90° C. at the start; at 8.30 on the morning after the run it was at 350° C. The metal was poured at 1,200° C. average. In this table the center compartment is called No. 2, the end compartments Nos. 1 and 3. As in the previous tests, the crucibles were charged with all the metal they would hold (in small ingots), after pouring a heat, before returning them into the furnace, and the remainder was added as soon as the metal in the crucible had melted down enough to make room for it.

In Table 10 the time given, after the start, is the time at which a pot was taken from the furnace to pour.

TABLE 10.—Log of run on furnace 6 (triple No. 20).

Time.	Pounds poured from compartment No.			Kw. h. used in time intervals given.	Total kw. h. used so far. ^a
	1	2	3		
7:30	Start.	Start.	Start.		0
7:50		61		110	110
8:15		61½		46	156
8:30		61½	61½	26	182
8:45		61½		11	193
8:51		61		8	205
8:52	61	60		23	228
8:54					
9:00				23	251
9:05					
1:29		61½		7	258
1:45		60	60	28	286
2:15		60		27	313
2:36	67½			9	324
3:05		61		24	348

^a Average, 31 Kw. h. per 100 pounds.
^b Power off for 10 min.
^c Power on.

TABLE 10.—*Log of run on furnace 6 (triple No. 20)—Continued.*

Time.	Pounds poured from compartment No.			Kw. h. used in time intervals given.	Total kw. h. used so far.
	1	2	3		
<i>p. m.</i>					
3.10.....			60½	4	352
3.51.....		61		25	377
4.33.....			61½	14	391
4.39 ^d		60		19	410
4.43.....	70			0	410
Totale.....	198½	547½	252½		

^d Power off.

• 998 pounds poured.

The resistor between compartments 2 and 3 was evidently generating more heat than that between compartments 1 and 2, as only three heats were obtained in compartment No. 1 against five in No. 3. This was remedied in later tests by connecting a voltmeter to show the voltage drop across either resistor and by adjusting the blade pressure until each row of blades gave the same voltage drop. This test on furnace 6 was run one hour longer than that given above on the single No. 20 furnace (No. 1) in order to stop when all three pots had been poured within 10 minutes. The power was off furnace 1 for one and one-fourth hours instead of one-half hour. Had furnace 1 been run one and three-fourths hours more it would have produced three more 55-pound heats, or a total of 11, and would have used a total of 420 kilowatt hours.

We can then compare the single No. 20 (furnace 1) and the triple No. 20 (furnace 6) as follows:

Operation.	Output.		Kw. h. per ton.	
	Single.	Triple.	Single.	Triple.
9-hour operation.....	Pounds. 565	Pounds. 1,000	1,500	820
24-hour operation.....	1,800	4,000	1,000	700

The advantage of the triple furnace is even more marked when we consider that on 9-hour operation 420 kw. h. would produce 565 pounds of metal in the single furnace, whereas the triple 410 kw. h. produced 547½ pounds in the center compartment alone, as well as 450 pounds from the end compartments.

The directing of the heat from the outside of the resistors toward other crucibles instead of toward walls made much of that heat do

useful work and did not decrease the work done in the center compartment. The improvement doubtless would not be so striking in a furnace of larger size nor on continuous operation, but it would be decided.

In order to see if any saving could be made by keeping the furnace hot at night, in another test the furnace was run empty at a low power input for five hours, using a total of 161 kw. h. The melting chamber came up to $1,150^{\circ}$ in two and one-half hours, using 98 kw. h., and was held there two and one-half hours by the use of 63 kw. h. more, or an average power input of 25 kw. Melting was then begun, four heats of 60 pounds each being made in two hours (two from the center compartment, one each from the ends) using 93 kw. h. The metal was poured at $1,200^{\circ}$ C., the regular alloy being used.

The furnace was probably nearly but not fully heated to the "stationary state" or "steady state," in which the inside is at full running temperature, the walls are so heated that they no longer absorb and store heat on further running, and the outside of the furnace being at maximum temperature the losses by radiation from the walls are highest. In the "steady state" the power supplied to the furnace either is usefully applied in melting or is lost by radiation, conduction, and convection from the wall and cover surface into the floor and from the electrodes by water cooling. None is fed to the walls to be stored there, as the walls take only the energy needed to maintain them throughout in a temperature equilibrium with the hot interior of the furnace and the cold air outside.

It was intended to supply power to the furnace through the night as needed to hold the temperature of the furnace constant, but the porcelain protecting tube of the pyrometer used for taking chamber temperatures was broken and the couple itself injured just as it was inserted, so that the power supply had to be adjusted by visual rather than pyrometric control of temperature.

From 3.12 p. m., when the last heat was poured, to 8 o'clock the next morning the furnace was run empty at about 10 kw., 163 kw. h. being used in the 16 hours. The furnace then appeared to be nearly but not quite at running temperature. To test this a few heats were taken off, as given in Table 11.

TABLE 11.—*Log of run on triple furnace, starting hot after running at night.*

Time.	Pounds poured from compartment No.			Kw. h. used in time intervals given.	Total kw. h. after 8 a. m. ^a
	1	2	3		
<i>a. m.</i>					
8.00.....	Start.	Start.	Start.		0
9.11.....	do.	61		63	63
9.43.....			60	30	93
9.49.....	59½			5½	98½
9.55.....		60½		5	103½
10.40.....		62½		38½	142
11.04.....	55½			18	160
11.08.....			60½	7½	167½
11.20 ^b		59½		7½	175
Total ^c	115	243½	120½		

^a Average, 36½ kw. h. per 100 pounds.^b Power off at 11.15; metal poured at 11.20.^c 479 pounds poured.

Calculated to a 24-hour operation basis, the triple furnace gave about 3,500 pounds output at 730 kw. h., a fairly close check on the figures calculated from the other test given above. The calculated output is somewhat too low and the power consumption somewhat too high, because the furnace was not fully hot at the start.

On a 9-hour basis, keeping the furnace hot the other 13 hours at 10 kw., it appears, considering both tests, that the figures would become about as follows: Output in 9 hours, 1,400 pounds; kw. h. in 9 hours' running, 420; in 13 hours, empty, 130; total, 550, or 890 kw. h. per ton. The power cost per ton therefore would be about the same as on 9-hour operation without night heating, but the output would be increased 40 per cent.

The best method of operation can not be calculated accurately from such runs as these; it must be worked out by actual long-time tests. The triple No. 20 furnace did not do quite as good work as the single No. 40 furnace, as would be expected, because the triple furnace had greater wall area and more waste space than the single No. 40.

The Hoskins Manufacturing Co. later built a double furnace for two No. 20 crucibles in which nickel-chromium alloys were melted, in which there were two rows of resistor plates along the long sides of the rectangular furnace and two crucibles set side by side in the same chamber. Exact data are not available. It is said to have shown a materially decreased power consumption over the use of two separate No. 20 furnaces, but not as much decrease as was shown by the bureau's triple furnace over the single one.

OBJECTIONS TO CRUCIBLE FURNACES TESTED.

Aside from the general disadvantages of crucible furnaces—small units, cost of crucibles, and high cost of labor—the main objection is the short life of the resistor plates. At prewar prices the plates cost

about 3 to 5 cents apiece, according to size, and would be more expensive now. In the practice of the Hoskins Manufacturing Co. on melting nickel-chromium alloys the plates are replaced every Sunday or every other Sunday, when the furnaces are regularly used 9 or 10 hours a day, in order to avoid shutdowns during the week. The electrodes, end blocks, and connector plates also have a relatively short life. The failure of the carbon and graphite parts is due to the entrance of air when the furnace is opened to charge or pour and to leakage of air, while running, if the furnace is not tightly closed.

Sufficiently exact data were not obtained to give the true cost of carbon parts per ton of metal melted, but at prewar prices it appeared probable that even on the larger furnaces the cost would lie between \$1 and \$2 per ton. At any rate, it would be a considerable item of expense, and it was necessary to see if it could be reduced. Through the kindness of the National Carbon Co. some plates were obtained in which a carborundum rim was molded around the plate, forming a sort of "picture frame" of carborundum. Through the courtesy of the Carborundum Co. the edges of some plates were subjected to silicon vapor (the "siliconizing" process)⁷³ and a layer of "silundum" or "silfrax" formed thereon. These with plain companion plates were all put in a furnace which was run as follows, cooling to room temperature, with the furnace closed, between each heating:

TABLE 12.—Times and temperatures of run on protected resistor blades.

Run No.	Hours heating.	Furnace empty or melting.	Maximum temperature of furnace.	Temperature of metal poured.
			°C.	°C.
1.....	3	Empty.	1,350	.....
2.....	1½	do....	1,075	.....
3.....	1½	do....	1,000	.....
4.....	7½	Melting.	.....	1,200
5.....	½	Empty.	600	.....
6.....	3	Melting.	.....	1,300
7.....	1	Empty.	800	.....
8.....	2	Melting.	.....	1,000
9.....	9	do....	.....	1,075

Average weights after a total running time of 28½ hours.

	Average original weight.	Average final weight.	Average loss.	Loss.
	Grams.	Grams.	Grams.	Per cent.
Small carbon.....	92	36	56	60
Large carbon.....	139	61	78	56
Small "picture frame".....	111	62	49	44
Large siliconized.....	122	78	44	36

⁷³ Compare Toner, F. J., U. S. Patent 1,013,700, Jan. 2, 1912; Carborundum refractories: Met. Chem. Eng., vol. 11, 1913, p. 485.

The protecting coat tended to crack off from both sorts of protected plates rather early in the test. While such protection does increase the life, it probably does not increase it enough to make up for the increased cost. Protection of the plates by placing them inside a trough or box made of thin carborundum slabs, as was done on furnace 6, was a much more effective way of preventing oxidation of the resistor. Baffling the flow of heat by a solid wall is inadvisable from the point of view of thermal efficiency and might be expected to reduce the efficiency materially. In the triple furnace, however, there was no perceptible difference between the furnace with open blades and with blades in the carborundum box, either on rate of production or on power consumption.

Granular graphite was tried as a resistor material in the triple furnace, held in carborundum troughs, but it was not found possible to maintain the resistor in a tall narrow trough, as hot spots sooner or later developed. On making the troughs sufficiently wider and shallower to minimize that difficulty the voltage, even with the wider and shallower trough, had to be kept below a certain limiting value for each different resistor or the hot spots would again develop. The triple furnace was rated at 50 kw. and in order to get resistors in 12-inch lengths (2 resistors in series) that would take 50 kw. it was necessary to use troughs 7 inches wide by $4\frac{1}{2}$ inches deep, inside dimensions, filled evenly with 14-mesh graphite and covered with carborundum slabs. This resistor when fully hot took about 40 volts at 1,250 amperes. Coarser graphite would probably have caused less danger of hot spots, but none was available. The resistors were now each 8 inches wide outside instead of about 4 inches, as were the carborundum boxes inclosing carbon plates; hence it seems that the waste space and the 8 inches added length demanded by the substitution of granular resistors would be likely in so small a furnace to lower the efficiency of the furnace.

A few tests were also made on the construction of crucible furnaces of the multiple type, in which an arc is used as the heat source, but when an arc (between the two electrodes) is run near an ordinary graphite crucible bonded with clay the excessive local arc temperature soon melts the bond and makes the crucible disintegrate.

BOCUZE FURNACE.

Bocuze⁷⁴ has suggested a furnace in which a crucible rotates on its vertical axis and is heated by two arcs, one on each side, which move up and down, the motion of the crucible and arc distributing the heat uniformly over the surface of the crucible. This plan appears to require an unusual amount of mechanism for the heating

⁷⁴ Bocuze, J. M., U. S. Patent 1,053,563, Feb. 18, 1913.

of one crucible, and such a furnace would therefore be expensive to build.

Attempts were made by the Bureau of Mines to heat a furnace containing two crucibles between which was one arc separated from the crucibles by carborundum slabs to distribute the heat more uniformly; the carborundum, however, was raised to its decomposition point near the arc before the crucibles were hot enough to melt brass.

The bureau's work on crucible lift-out furnaces indicated (1) that, although metal losses for alloys high in zinc were much less in electric crucible furnaces than in fuel-fired furnaces, and (2) although the efficiency of crucible lift-out furnaces could be increased by the use of multiple furnaces arranged for internal heating, with resistors between the crucibles, in place of a single crucible with resistors along the walls, nevertheless (3) the crucible furnace can not be made to compare in efficiency with furnaces of the hearth type. The cost of crucibles, also, and the fact that at best the crucible type is a small-unit furnace, made it advisable to turn to other forms of electric furnace.

FACTORY TEST OF NO. 70 HOSKINS FURNACE.

In the meantime a test on melting brass was made by the Hoskins Manufacturing Co. at its own factory in a larger-size furnace than those described above, a representative of the Bureau of Mines being present. This furnace is shown in Plate III, *B* (p. 51).

ARRANGEMENT OF FURNACE.

The lift-out furnace, called the "F. C. 108" furnace, was built up in an iron shell 43 by 43 by 29 inches. The furnace chamber proper inside this shell was 19 by 19 by 16 inches high. About this was a lining of magnesite brick $4\frac{1}{2}$ inches thick, backed up by a $2\frac{1}{2}$ -inch layer of fire brick on the sides and by $8\frac{1}{2}$ inches of fire brick on the bottom. About the sides, the space between fire brick and shell, 5 inches on each side, was packed with infusorial earth. There was a square hole $2\frac{1}{2}$ by $2\frac{1}{2}$ inches in the bottom of the furnace to allow the metal to run out if the crucible should break in the furnace. This was closed with a fire-clay plug at the bottom.

The resistor consisted of two rows of carbon blades $2\frac{1}{4}$ by 15 by $\frac{1}{4}$ inches, standing at opposite sides of the furnace. There was just room in the furnace chamber for a No. 70 crucible. The tongs were put on diagonally, the corners allowing space for them. A No. 70 crucible is rated at a capacity of about 210 pounds of red brass, or about 195 pounds of yellow brass. The hoist used to lift the crucible

was a little difficult to handle and the metal was likely to spill into the furnace during the lifting of the crucible if filled too near the top. The electrodes were graphite cylinders 3 inches in diameter. These were laid in a carborundum fire-sand packing and pressed against contact blocks of graphite $2\frac{1}{4}$ by $2\frac{1}{4}$ by 15 inches, which, in turn, pressed against the blades. At the other end of the electrodes water-cooled electrode holders made contact with flexible laminated copper connectors, to which the leads were joined. The electrode holders were provided with adjusting screws by which the contact resistance between the blades could be varied by varying the pressure. The two rows of blades, about 60 blades on a side, 120 in all, were joined in series through three carbon plates $1\frac{1}{2}$ inches thick, 5 inches high, and 19 inches long. As there is no contact resistance on this side, the carbon plates, though forming part of the resistor, have a lower resistance than the blades and generate little heat. On the electrode side of the furnace the furnace chamber was lined with magnesite brick, standing between the two graphite contact blocks or "push blocks." Thus the melting chamber had magnesite on one side, high-resistance resistors on two sides, and low-resistance resistor on one side. The heat was generated mainly in the sides with the two high-resistance resistors and was not evenly distributed about the crucible.

The furnace chamber was raised 4 inches above the furnace shell by large fire-brick blocks about 2 by 1 by 4 feet, so laid as to project $2\frac{1}{4}$ inches over the resistor blades, at 1 inch distance above them. This distance is rather small, and the fire brick began to drip a little at the end of the tests, although no serious trouble resulted. The projecting ledge served to protect the tops of the blades from oxidation and the operator from some of the direct radiation when he pulled the crucible from the furnace.

The fire-brick blocks were not tightly laid, and the iron shell might well have been 4 inches taller. The fire-clay plug in the drainage hole in the bottom was not tight, and there was some draft through the furnace from top to bottom, as the furnace was not properly closed. This draft hastened oxidation of the blades and increased the zinc loss from volatilization. On top of the massive blocks was a cover of 4-inch fire brick, with a charging hole in the center, that was in turn covered with fire brick.

DETAILS OF TEST.

The run on May 5, 1914, began at 10.15 a. m., the furnace being cold. The metal melted on this day was yellow brass ingot containing 66 per cent copper, 33 per cent zinc, and 1 per cent lead. The first two charged were of ingots weighing about 30 pounds each. The

metal was poured into smaller ingots weighing about 10 pounds each. The transformer efficiency was not known, but it was probably not as high as on ordinary transformers, as a special testing set of transformers had been designed for ready control by a number of changes in voltage rather than for efficiency. Calculating transformer efficiency at 100 per cent, the furnace was started on 234 volts, 240 amperes, 55 kv. a. on the primary, and 42.5 volts, 1,300 amperes, on the secondary. As the resistor warmed up the power taken increased, till in half an hour the primary showed 220 volts, 390 amperes, 85 kv. a., corresponding to 40 volts, 2,150 amperes, on the secondary. This was too high a current for the leads, which began to heat up, as the leads consisted of four cables, each of about 300,000 circular mils. Each of these two leads was about 6 feet long. The transformer ratio was changed at 10.57 a. m., so that for 220 volts, 390 amperes, 85 kv. a. on the primary, the secondary was taking about 45.5 volts, 1,750 amperes. About 90 pounds of metal had been charged at the start, and it took till noon, or $1\frac{3}{4}$ hours, before this had melted down so that another 30-pound ingot could be charged. Up to noon 130 kw. h. had been used. (The watt-hour meter being of course connected on the primary all kw. h. figures include transformer and lead losses.) The heat went on more rapidly from that point, till at 12.23 p. m. the charge, totaling $181\frac{1}{2}$ pounds of metal, was all in. The furnace was run at an average of 85 kw. until 12.30 p. m., when the power was reduced by regulation of the blade pressure to about 80 kw., at which figure it ran till 12.39; it was then reduced further to 40 kw., and then progressively to 15 kw. at 12.45, when the metal was at $1,060^{\circ}$ C. and the heat was poured. The heat took $2\frac{1}{2}$ hours and used 183 kw. h., or 101 kw. h. per 100 pounds on the first heat from a cold furnace. The men who poured the metal into ingots were not used to crucibles of this size and spilled a good deal, increasing the gross loss. There was poured $176\frac{1}{4}$ pounds of ingot, and $4\frac{1}{2}$ pounds of clean metal were recovered from spillings and skimmings. The net loss was thus 0.4 per cent. A little salt was used as a flux on this heat and on subsequent heats.

The power was kept on between heats, but the adjusting screws were loosened, so that not much power was drawn by the furnace. The power thus used while the furnace was empty is charged to the heat next following. The other heats will not be described in detail, but are tabulated in Table 13.

TABLE 13.—*Test of Hoskins furnace, No. 70 crucible, on yellow-brass ingot.*

Heat No.	Time current on.	Current off.	Amount charged.	Ingot poured.	Metal recovered from spill and skim.	Total.	Net metal loss.	Pouring temperature.	Kw. h. used.
			<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>		<i>Pounds.</i>	<i>° C.</i>	
1.....	10.15 a. m.	12.45 p. m.	181.50	176.25	4.5	180.75	0.75	1,060	<i>a</i> 183
2.....	12.55 p. m.	1.56 p. m.	188.25	183.00	4.5	157.50	.75	1,065	78
3.....	2.04 p. m.	2.57 p. m.	194.00	(<i>b</i>)				1,065	75
4.....	3.15 p. m.	4.03 p. m.	192.00	186.50	4.0	190.50	1.50	1,060	68
5.....	4.10 p. m.	4.42 p. m.	107.50	104.00	3.0	107.00	.50	1,065	46
Total.....			863.25				<i>c</i> 3.50		<i>d</i> 450

a Furnace cold at start.*b* Much metal spilled into furnace in lifting pot.*c* Net metal loss on 669.25 pounds, 3.50 pounds, or 0.52 per cent.*d* That is, 1,010 kw. h. per ton.

At 5.06 p. m. the outside wall of the furnace was at 80° C. At 7.10 the next morning it was at 70° C., and the melting chamber was at 600° C.

On the next day, May 6, with the furnace hot from the previous day's run, a red brass containing 33 per cent copper, 4 per cent tin, 5 per cent lead, and 7 per cent zinc was melted. Using the same transformer ratio as was used at the last (and during most of the run of May 5), the furnace was started at 7.20 a. m., taking 53 kw. As the resistor became heated more power was drawn, till at 8.50 a. m. it had reached 92.5 kw.; from this point it was run at 80 to 85 kw.

Seventy-five pounds of metal (in 25-pound ingots) was charged at the start. No more could be charged till 8.40 a. m., and the whole charge of 202½ pounds (all in about 25-pound ingots) was in at 9.09 a. m.. At 9.20 a. m. the metal was at about 1,050° C., and at 9.36 a. m. it was at 1,200° C., when it was poured. This heat and the later heats are tabulated in Table 14.

TABLE 14.—*Test of Hoskins furnace, No. 70 crucible, on red-brass ingot.*

Heat No.	Time current on.	Current off.	Amount of ingot charged.	Ingot poured.	Metal recovered from skim and spill.	Total.	Net metal loss.	Pouring temperature.	Kw. h. used.
			<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>		<i>Pounds.</i>	<i>° C.</i>	
1.....	7.20 a. m.	9.36 a. m.	202.50	198.25	3.25	201.50	1.00	1,200	<i>a</i> 164
2.....	9.45 a. m.	10.40 a. m.	203.00	(<i>b</i>)				1,200	79
3.....	10.53 a. m.	11.45 a. m.	192.25	189.00	2.00	191.00	1.25	1,200	70
4.....	11.55 a. m.	<i>c</i> 12.55 p. m.	196.00	194.50	1.00	195.50	.50	1,200	<i>c</i> 47
5.....	1.04 p. m.	1.50 p. m.	193.75	192.00	1.25	193.25	.50	1,180	<i>c</i> 65
6.....	1.57 p. m.	2.41 p. m.	193.50	188.75	4.25	193.00	.50	1,200	48
7.....	2.47 p. m.	3.33 p. m.	192.00	190.00	1.50	191.50	.50	1,180	49
8.....	3.40 p. m.	4.27 p. m.	190.00	187.50	2.00	189.50	.50	1,180	48
Total.....				1,563.00			<i>d</i> 4.75		<i>e</i> 570

a Furnace warm at start from previous day's run.*b* Pot too full; metal spilled into furnace in lifting.*c* Low power for 20 minutes and none at all for 12 minutes (noon heat) while metal was in crucible. Note reduction in kw. h. used because of use of stored heat, which had to be replaced on next heat.*d* Net metal loss on 1,360 pounds, 4.75 pounds or 0.35 per cent.*e* Average, 730 kw. h. per ton.

The results on red brass, starting with a warm furnace, are much better than on the run of five heats on yellow brass, starting with a cold furnace. With the furnace hot in the morning from a previous day's run, the power consumption for yellow brass would apparently be about 600 kw. h. per ton. The crucible was in far better shape after 13 heats in the electric furnace than it would have been after 13 heats in a fuel-fired furnace. The efficiency of the No. 70 furnace was only a very little, if any, better than that of the No. 40 furnace, although the larger furnace would be expected to show better results. The relatively better results of the No. 40 furnace are probably due to the use of resistor plates on four sides of the crucible instead of on two only. There was a visible difference in temperature in the No. 70 size between the sides on which the resistors were placed and the other two sides.

FOUNDRY TEST OF NO. 70 HOSKINS FURNACE.

In order to collect information on electric brass melting, the Commonwealth Edison Co., of Chicago, purchased a Hoskins furnace designed to take a No. 70 crucible, installed it, and tested it at the plant of the L. Wolff Manufacturing Co. The test was conducted by Mr. H. M. St. John, of the Commonwealth Edison Co., in 1915, by whose courtesy the following data are made available.

The furnace was in actual operation 40 days, in which it produced 171 heats of about 200 pounds each, or about 17 tons of metal. This is an average of only a little over four heats a day, but does not represent the productive capacity of the furnace, as operation was on an experimental basis.

RELIABILITY.

During the test the furnace had to be shut down eight times for furnace troubles, four times when the breaking of a crucible let the metal into the furnace chamber, twice for failure of cover slabs, once for failure of the magnesite lining, and once for failure of the resistor.

The crucible breakage was apparently due to the use of a No. 80 crucible in a furnace only designed for a No. 70, thus bringing the crucible very close to the resistor. Vertical cracks developed at the top of the crucibles, apparently due to too rapid heating of the parts of the crucible nearest the resistor. The crucibles averaged a life of only 19 heats, against a record of 35 heats claimed for the same crucibles in the oil furnaces of the plant. There was much less oxidation and scaling in the electric than in the oil furnaces; if the cracking could be prevented the crucible life in the electric

furnace should be superior. It seemed probable that by using resistor plates on all four sides of the furnace instead of on two only and by using the No. 70 crucible, for which the furnace was intended, a more even heating of the crucible and a satisfactory crucible life would result.

A larger, more easily opened tap hole in the furnace bottom could readily be installed, and shutdowns thus avoided if a crucible did break in the furnace. The shutdowns due to failure of the cover bricks could be prevented by using a better grade of brick or by keeping spare covers on hand.

The magnesite-brick lining was not a success, as under the intermittent operation of the test it spalled badly after two weeks' service. It was patched up and kept going throughout the test, but it was a cause of continual anxiety. Inasmuch as the Hoskins Manufacturing Co. had very good results from furnaces with carborundum linings in melting nickel-chromium alloys, and hence run under more severe conditions than a brass furnace, it was believed that by replacing the 4½-inch magnesite lining by one made of 2¼-inch magnesite and 2½-inch carborundum, with the carborundum inside, the life of the lining could be made satisfactory.

Shutdowns from failure of the resistor or other carbon parts can be prevented by replacing such parts on the Sunday before they would fail. Experience is needed to enable the operator to predict just when failure would occur; with such experience, shutdowns should be infrequent.

While it was impossible to make, during the test, the changes indicated by the test as desirable, there seemed no reason why the furnace should not operate steadily and reliably if the suggested improvements should be made.

EFFICIENCY.

The furnace could not be run at maximum efficiency, as it was placed so far from the molding floor that the metal had to be carried much farther than would be necessary in practice. This meant that the metal had to be heated more than normal and that the loss of time in pouring was much more than should be, probably handicapping the furnace about one heat in a 9-hour day. Operating on yellow brass of 65 per cent copper, 33 per cent zinc, and 2 per cent lead, with the metal poured at 1,100,° C., the average results shown in Table 15 were obtained.

TABLE 15.—*Results of foundry test of Hoskins furnace, 200-pound heats.*

Monday, starting with furnace practically cold.

Heat No.	Time of heat. ^a	Kw. h. used.	Output.
	<i>H. m.</i>		
1.....	2 42	209	<i>Pounds.</i> <i>b</i> 1,200
2.....	1 26	96	
3.....	1 20	91	
4.....	1 10	76	
5.....	1 10	72	
6.....	1 05	66	
Total.....	8 53	610	

Regular operation, no night heating, but furnace hot from previous day's run.

	<i>H. m.</i>		
1.....	2 10	162	<i>Pounds.</i> <i>c</i> 1,400
2.....	1 22	91	
3.....	1 18	79	
4.....	1 10	77	
5.....	1 10	68	
6.....	1 05	62	
7.....	1 00	58	
Total.....	9 15	597	

Saturday (half day).

	<i>H. m.</i>		
1.....	2 10	162	<i>d</i> 600
2.....	1 22	91	
3.....	1 18	79	
Total.....	4 50	332	

^a Actual running time per heat, plus 10 minutes to pour and charge.^b 1,000 kw. h. per ton.^c 75 kw. h. per ton.^d 1,100 kw. h. per ton.*Results of a week's operation.*

	Output.	Kw. h. used.
	<i>Pounds.</i>	
Monday.....	1,200	610
Tuesday to Friday.....	5,600	2,385
Saturday.....	600	332
Total.....	7,400	^a 3,330

^a 200 kw. h. per ton.

By using 125 kw. h. during the night (about 8 kw.) to keep the furnace hot, the following results were obtained:

Results of heats.

Heat No.	Time of heat. ^a	Kw. h. used.	Output.
	<i>H. m.</i>		
0.....	(^b)	125	
1.....	1 44	136	
2.....	1 19	91	
3.....	1 18	77	
4.....	1 06	75	
5.....	1 03	71	
6.....	1 00	68	
7.....	1 00	c 55	Pounds.
8.....	1 00	51	d 1,600
Total.....	9 30	749	

^a Actual running time per heat, plus 10 minutes to pour and charge.

^b Night.

^c Power input reduced on last heat, utilizing some stored heat.

^d 950 kw. h. per ton.

Night heating at this rate increases the output by one heat, but raises the energy needed per ton. Eight kw. are insufficient to hold the furnace hot enough over night to affect materially the production rate.

On a 24-hour operation the furnace could produce 200 pounds per hour, or 4,800 pounds per day, at 55 kw. h. per heat, or 550 kw. h. per ton.

About 10 per cent of the power supplied (about 80 kw. on the first couple of heats of a 9-hour day, about 60 kw. thereafter) was lost in the electrode cooling water.

ELECTRICAL CHARACTERISTICS.

Like any purely resistance furnace, the power factor was unity. Under usual operation the voltage and amperage for different rates of power were as follows:

TABLE 16.—Comparison of current values.

Kw.	Volts.	Amperes.	Kw.	Volts.	Amperes.
100	50.0	2,000	75	41.7	1,800
90	47.4	1,900	70	41.2	1,700
85	47.2	1,800	65	40.7	1,600
80	45.8	1,750			

By varying the pressure on the plates at any given voltage the power input can be varied 25 per cent and still give good operating conditions. Larger variations could be made, but result in less satisfactory operation, so that voltage control is also necessary.

Where resistor plates are used on four sides of the furnace instead of two, there would be a greater allowable percentage of power regulation by altering the resistor pressure, the voltage would be

increased, the current lowered, and hence the power loss in electrode-cooling water decreased and the efficiency raised somewhat.

LIFE OF CARBON PARTS.

The average working day's life of the various carbon parts was as follows: Carbon resistor plates and graphite back plates, 12 to 14 days; graphite push blocks and electrodes, 24 to 30 days.

METAL LOSS.

Only a few determinations of metal loss were made. On the yellow brass (33 per cent zinc) used, the charge containing 12 per cent oily borings and 18 per cent gates, with some adhering sand, the average net loss, by comparing weight of metal charged and weight of ingot poured ($1,100^{\circ}$ C.), was 1.1 per cent, no deduction being made for the nonmetal in the charge. By weighing the charge and weighing the crucible full of molten metal before and after pouring in order to get the weight of metal in the pot, a net loss of 0.3 per cent was found on the yellow brass. The latter method, on a few heats of red brass (20 per cent oily boring and 13 per cent gates) gave 0.35 per cent net loss. The net loss on yellow brass in the crucible lift-out oil furnaces ran between 3 and 4 per cent.

The castings made with electrically melted metal were subjected to regular inspection and to hydraulic tests and were reported to be of the same quality as metal from the oil-fired crucible furnaces.

A comparison of melting costs was made for yellow brass, as follows (1915 conditions):

TABLE 17.—*Comparative melting costs with oil and electric crucible lift-out furnaces.*

Oil Furnace.	
44 gallons oil per ton, at 4 cents per gallon.....	\$1. 76
Pumping oil and blowing air.....	. 50
Maintenance	. 25
Metal loss 3 per cent, at 10 cents per pound.....	6. 00
Labor.....	1. 10
Crucibles at \$5.25 each, life 35 heats of 200 pounds.....	1. 50
Total	11. 11

Electric Furnace. •	
9-hour operation, no night heating:	
Power, 900 kw. h. per ton at 1 cent per kw. h.....	\$9. 00
Maintenance (resistors, linings, etc.)	1. 00
Labor (same as in oil furnace).....	1. 10
Crucibles (life assumed same as in oil).....	1. 50
Metal loss 1 per cent, at 10 cents per pound.....	2. 00
Total	14. 60

Electric Furnace.—Continued.

24-hour operation:

Power, 550 kw. h. per ton at 1 cent per kw. h.-----	5. 50
Maintenance -----	1. 00
Labor -----	1. 10
Crucibles -----	1. 50
Metal loss -----	2. 00
Total -----	11. 10

The better working conditions resulting from the use of the electric furnace, due to its great cleanliness, quiet, and coolness, compared to the oil furnaces are not assigned pecuniary valuation in the above comparison, although the advantages were apparent. These factors were assumed to balance the interest and depreciation charges on the electric furnace, which were not included in the calculation. The price of a furnace, taking a No. 70 crucible, with complete auxiliary equipment ready to attach to a 110-volt, 60-cycle current (but not including transformer for stepping down from 2,200, 4,400, or 6,600 volts to 110 volts), on August 1, 1916, was about \$1,500. It is seen that for the electric crucible lift-out furnace to compete with an oil furnace at these figures the electric furnace must be used 24 hours a day and must be developed to equal or surpass the oil furnace as regards crucible life. Even then, at the assumed prices of oil and of electric power, the only opportunity for the electric crucible furnace is its reduction of losses in metal. The higher the value of the metal lost the greater is the chance for the electric furnace.

It is obvious that under the 1915 conditions at the plant the electric crucible furnace was not promising and the furnace was not used after the test, nor was the test continued to try out the improvements suggested.

CADWELL FURNACE.

A crucible lift-out furnace designed by Cadwell,⁷⁵ primarily in portable form for melting copper for bonding purposes on an electric railroad, and hence made to utilize current from the trolley wire or third rail, contains one or more small crucibles resting on (but not surrounded by) a bed of granular carbon, to which the granular resistor current is led by two vertical, adjustable electrodes. From these electrodes arcs are drawn to the resistor, so that the crucible is heated by radiation from arcs on two sides and by conduction and radiation from the resistor below.

Further details of the design will be found in the patent. It is stated that two crucibles, each containing 20 pounds of copper, may be brought to 1,375° C. in 20 minutes, but it is not stated whether

⁷⁵ Cadwell, . A., U. S. Patent 1,290,902, Jan. 14, 1919; application filed May 1, 1915.

this refers to starting from the cold or to starting with the furnace already up to temperature. No data on power consumption, furnace upkeep, etc., are given.

RENNERFELT CRUCIBLE LIFT-OUT FURNACE.

A recent patent to Rennerfelt⁷⁶ for a multiple-crucible lift-out furnace for melting metals, glass, etc., is of interest, although no data on its operation are available. In this furnace is used the principle of internal heating previously utilized in the triple-crucible furnace tested by the Bureau of Mines. The heating element of the furnace is in the center, and crucibles are placed all around it in a circular furnace or on both sides of it in a rectangular furnace.

The heat is generated by arcs struck from three vertical, adjustable electrodes, in a three-phase furnace, to a bed of granular carbon or graphite held in a dish-shaped carbon or carborundum receptacle in the circular furnace, or in a trough of one of those materials in the rectangular furnace. The presence of the granular resistor material stabilizes the arcs, and some heat is generated by the passage of current through the resistor.

As to the source of heat, then, the furnace would be classed as a combination smothered-arc, granular resistor furnace. While some heat is radiated directly to the crucibles, it is mainly radiated from the arcs and from the resistor to the roof, from which it is reflected downward by the arched or domed roof. The central part of the roof directly over the heating element will receive extremely severe treatment, as is recognized by the inventor, who stipulates that carborundum, zirconia, or similar extremely refractory materials should be used in those parts of the furnace receiving direct radiation. Instead of using a sectional roof, with openings through which to withdraw the crucibles by direct vertical lifting, openings in the sides of the furnace are provided for taking out each crucible as well as for charging it. This detail would make a special pair of tongs with an extension arm necessary for thrusting the tongs into the furnace and also a counterbalance on the other side of the hoist hook, so that the crucibles might be taken out.

From the point of view of thermal efficiency alone this design is probably one of the best that has been suggested for an electric crucible lift-out furnace. Aside from the danger of short life in the roof, the main questions, which could be answered only by experiment, are whether the crucibles heated primarily from one side by a source of high temperature of heat will show a reasonable life and whether the heating from the top would not give rise to the same trouble from top heating on yellow brass that was encountered in

⁷⁶ Rennerfelt, L., U. S. Patent 1,313,834, Aug. 19, 1919; application filed May 12, 1919.

the Bureau of Mines experiments on the Hoskins type furnace 5 in using a tall, cylindrical crucible more strongly heated at the top than at the bottom.

If such difficulty is encountered in the design shown in the Rennerfelt patent, it might be reduced by raising the crucibles higher in the furnace, obtaining thus more direct heating on the sides of the crucibles.

If any alloys are found which it is metallurgically impossible to handle in an electric hearth-type furnace and if an electric crucible lift-out furnace is to be tried, the Rennerfelt idea—worked out with care in lining the furnace with the most refractory materials, in avoidance of excessive top heating, and in convenience in removing the crucibles—seems one of the most promising yet presented. The scheme has been worked out on a hearth-type furnace and will be referred to again under that heading.

GENERAL ELECTRIC CO. CRUCIBLE FURNACE.

The General Electric Co. has recently developed a small single-phase, 50-pound, 40-kw. crucible lift-out furnace in which heat is developed by the principle of contact resistance, which will be described in connection with the General Electric hearth-type brass melting furnaces. This is designed for use in metallurgical laboratories by manufacturing jewelers or by manufacturing concerns so situated that they can not use fuel-fired furnaces, as in a loft building of a large city. In other words, it is designed for users who melt relatively small amounts of nonferrous metals under such conditions that a high-power consumption is immaterial. The furnace is not claimed to be efficient, as its rate of melting copper (heated to $1,300^{\circ}\text{C.}$) on 24-hour operation, with the furnace fully heated up, is given as 700 to 800 kw. h. per ton.^{76a}

PFRETZSCHNER FURNACE.

A furnace of which nothing is known beyond the patent specification is described by Pfretzschner.⁷⁷ A crucible rests on one electrode, and another electrode, coated with electrically insulating material for melting materials that are conductors, is located inside the crucible and by a screw device exerts variable pressure on the bottom of the crucible. The bottom of the crucible, and to a certain extent the upper electrode, are supposed to act as resistors. Thus the crucible is heated from the bottom. After the charge is melted the upper electrode is raised and the crucible lifted out. It does not seem possible to operate such a furnace, as the amperage required

^{76a} Anonymous, Muffled-arc electric furnace for nonferrous metals: *Iron Age*, vol. 107, 1921, pp. 985-1047.

⁷⁷ Pfretzschner & Co., German Patent 244,171, class 21h, group 7, Mar. 1, 1912.

would be enormous, the voltage infinitesimal, and the chances very small of generating sufficient heat in the bottom to do any melting without ruining the crucible.

METAL LOSSES IN FUEL-FIRED PRACTICE.

It is quite impossible to make any accurate generalizations as to metal losses in fuel-fired practice. Figure 6 shows the data received

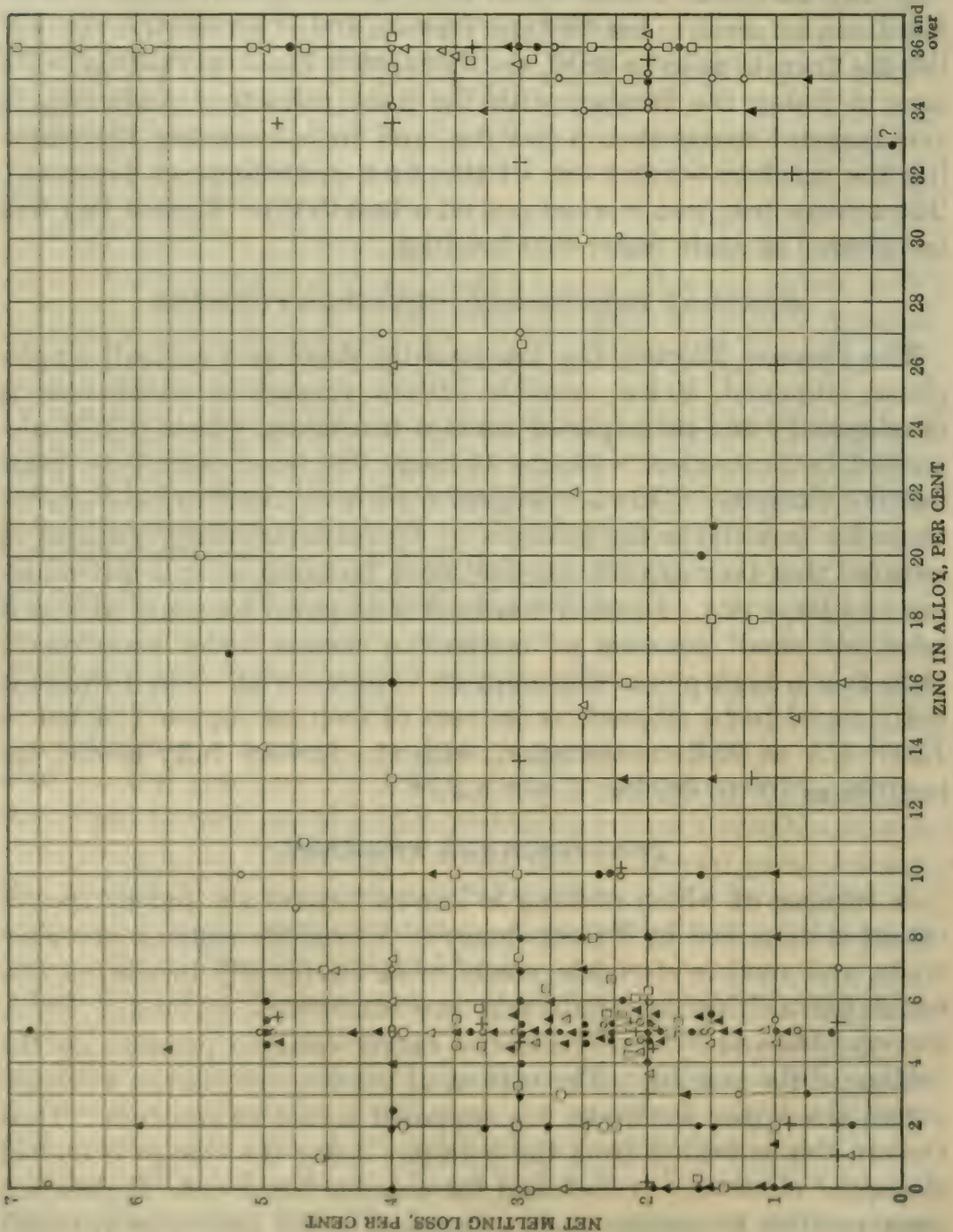


FIGURE 6.—Metal losses in fuel-fired furnace.

on this point in the preparation of Bulletin 73. The amount of fine material in the charge, the amount of nonmetallic material present, the rate at which products of combustion pass over the metal, the

area of metal surface exposed, the atmosphere in the furnace (reducing, neutral, or oxidizing), the time the metal is in the furnace, whether or not charcoal and fluxes are used, and the care taken in the operation of the furnace, as well as the composition of the alloy and the type of furnace, are all variables.

Nevertheless, to draw tentative conclusions, it might be said that from the evidence collected on fuel-fired practice the net metal losses on different alloys would average fairly close to those in Table 18, provided (1) that the type of fuel-fired furnace best adapted to give low metal losses were used for each alloy; (2) that each furnace were well operated; and (3) that suitable allowance were made for the nonmetallic part of the charge and for recovery of metal from ashes, spillings, and skimmings.⁷³

TABLE 18.—*Metal losses in fuel-fired furnaces.*

Composition of alloy, per cent.				Net metallic loss on new metal or ingot.	Net metallic loss on all borings.
Cu.	Zn.	Sn.	Pb.		
88	2	10	.....	<i>Per cent.</i> 1.0	<i>Per cent.</i> 1.5
85	5	5	5	2.0	2.5
80	10	5	5	2.25	3.0
75	16	3	6	2.75	4.0
65	32	.....	3	<i>a</i> 3.5	5.0
66	34	.....	.....	<i>b</i> 2.5	.....
60	40	.....	.....	4.0	10.0

a Foundry practice. *b* Rolling-mill practice.

Many plants may show poorer figures; a few may show better, but most managers are content if their average is as good as the data above.

The task set for the electric furnace, then, is to improve these figures. Data to show that the task has been accomplished will follow throughout this report.

METAL LOSSES IN BUREAU OF MINES EXPERIMENTS WITH CRUCIBLE LIFT-OUT FURNACES.

The foundry test on the Hoskins furnace previously cited emphasizes the importance of the reduction of metal losses in melting, as it was only the reduction of these losses that decreased the cost of melting to a point where there was any possibility of competing with fuel-fired furnaces. These losses on both the foundry and factory tests of the No. 70 Hoskins furnace were far lower than in fuel-fired practice. During the Bureau of Mines tests of the smaller Hoskins type of furnaces figures of metal loss were regularly obtained. Only

⁷³ See also Collins, E. F., Melting some nonferrous metals and their alloys in the electric furnace: Table 10, Chem. and Met. Eng., vol. 21, 1919, p. 679; Metal-loss figures in the brass foundry: Met. Ind. (London), vol. 15, 1919, p. 481.

a few of these figures are summarized here, as they merely corroborate the finding of low losses on the larger furnaces, and they did not differ in various sizes or forms of the crucible lift-out furnaces. In the tests of metal loss made by the Bureau of Mines the metal was poured into ingots. When oily borings were used, the amount of oil was determined and its weight deducted from the total weight of the charge.

TABLE 19.—*Metal losses in electric crucible lift-out furnaces.*

Heat, composition of charge, per cent.					Material.	Average pouring temperature.	Weight of metal charged	Weight of ingot poured.	Weight recovered from spillings.	Total weight recovered.	Loss.	Net loss.
Cu.	Zn.	Sn.	Pb.									
43 to 44....	100	.....	.....	.....	Ingot.....	° C.	Pounds.	Pounds.	Pounds.	Pounds.	Pounds.	Per ct.
45 to 46....	93.5	.....	6.5	.....	Borings.	1,225	73.25	72.80	0.40	73.20	0.05	0.07
47 to 49....	84.4	5.5	4.6	5.4	Oxidized millings passing 20-mesh.	1,100	96.00	95.85	.15	96.00	.00	.00
						1,120	147.00	144.50	a.50+	145.00	a 2.00	a 1.40
50 to 66....	78.5	16.0	2.5	3.0	Ingot.....	1,230	989.75	978.25	5.00	983.25	6.50	.66
98 to 110....	78.5	16.0	2.5	3.0	do.....	1,200	720.00	713.50	1.50	715.00	5.00	.70
111 to 120....	78.5	16.0	2.5	3.0	do.....	1,200	530.00	525.00	1.80	526.80	3.20	.61
67 to 69....	78.5	16.0	2.5	3.0	do.....	1,155	425.75	419.25	4.75+	424.00	a 1.75	a.41
70 to 72....	61.4	34.9	.....	3.7	Borings.	1,005	146.25	140.85	2.40	143.25	3.00	2.04
73 to 76....	62.5	33.8	.....	3.7	Ingot.....	1,075	198.15	195.20	2.00	197.20	.95	.48
77 to 83....	63	33.5	.....	3.5	do.....	1,060	870.30	861.25	6.10	867.35	2.95	.34
88 to 90....	55	40.5	.6	(b)	Turnings.	1,015	146.20	136.00	5.00	141.00	5.20	c 3.55

a Not all of spilled metal recovered.

b Also 0.40 per cent Al, 1.50 per cent Fe (manganese bronze); composition approximate—that aimed at in making up the alloy from which the turnings came.

c The ingot from heats 88 to 90 on manganese bronze turnings averaged, on analysis, 57.70 per cent Cu, 39.80 per cent Zn, 0.90 per cent Sn, 0.21 per cent Pb, 1.05 per cent Fe, 0.13 per cent Al, 0.04 per cent Mn. The analysis indicates that the zinc loss in melting will not account for the calculated net loss and make. It probable that the turnings carried dirt, which is here counted as metallic loss.

All these data compare very favorably with the figures assumed for fuel-fired practice and show that the higher the alloy is in zinc the greater the reduction in metal losses. This increase is to be expected, since the metal loss on alloys high in zinc is mainly due to volatilization of zinc rather than to oxidation. In fuel-fired furnaces there is always a flow of products of combustion over the metal which continually carries off zinc vapor, whereas in the electric furnace there is no flow of products of combustion and the furnace can be kept tightly closed.

In fact, even if the electric crucible lift-out furnace is not tightly closed at the top, as long as there is no opening in the bottom or sides of the furnace through which air can enter to cause a draft there is no appreciable escape of zinc vapor, as it is heavier than air and lies stagnant in the furnace until the cover is removed and air currents displace it. The metal can be so hot that it releases copious zinc fumes when the crucible is removed, and yet only the slightest escape of zinc fumes, or none at all, can be seen at small openings in the cover of the furnace.

TILTING ELECTRIC CRUCIBLE FURNACES.

Besides the lift-out furnaces described above various tilting crucible furnaces, electrically heated, have been suggested or tried.

STANSFIELD FURNACE.

Stansfield⁷⁹ shows sketches of crucible tilting furnaces for laboratory use in which a crucible, a relative nonconductor of electricity, is embedded in a granular resistor. In the earlier edition of his book he suggests that such a furnace could be made larger than the laboratory furnaces and could be used for brass or steel melting. The suggestion is omitted from the later edition.

EXPERIMENTAL BAILY AND OTHER FURNACES, WITH GRANULAR RESISTOR ABOUT CRUCIBLE.

It is not surprising that many experiments have been made on the use of crucibles embedded in a granular furnace which tilts to pour. When electric power is available for electric furnaces, the simplest method of making in the laboratory a small experimental heat of any ordinary material is to embed a crucible in a granular resistor, heat it, remove the crucible, and pour out the metal. Many such resistance furnaces for laboratories have been described,⁸⁰ and a German furnace of this type (the "Kryptol") has been sold in laboratory sizes.

As the resistor is disarranged by removing the crucible, it is obvious that the furnace should be tilted to discharge the contents of the crucible. The Bureau of Mines, in 1912, tried out some small tilting furnaces of this type. One furnace taking a No. 20 crucible started with a cold furnace and melted 50 pounds of copper in one hour, using 23 kw. h. A second 50 pounds was then melted in 35 minutes, using 14 kw. h. The copper was poured at 1,250° C. This fair-degree efficiency in so small a furnace, compared to the behavior of the first two heats on a No. 20 crucible lift-out furnace, which would take twice as long and use four times the power, shows the

⁷⁹ Stansfield, A., *The electric furnace* 1907, p. 22; 1914, pp. 26, 157.

⁸⁰ Compare Watts, O. P., *An electric furnace for heating crucibles*: *Electrochem. and Met. Ind.*, vol. 4, 1906, p. 273; Tucker, S. A., *A granular carbon-resistance furnace*: *Trans. Am. Electrochem. Soc.*, 1907, vol. 11, p. 307; Goodwin, J. H., *Granular carbon-resistance furnace*: *Met. and Chem. Eng.*, vol. 9, 1911, p. 188; Calhane, D. F., *A convenient furnace*: *Met. and Chem. Eng.*, vol. 8, 1910, p. 581; Calhane, D. F., and Bard, E. E., *An efficient electric furnace*: *Met. and Chem. Eng.*, vol. 10, 1912, p. 461; Lohr, J. M., *Tensile strength of copper-zinc alloys*: *Jour. Phys. Chem.*, vol. 17, 1913, p. 5; Jeffries, Z., *Notes on the gran-annular electric furnace*: *Met. and Chem. Eng.*, vol. 12, 1914, p. 154; Mitchell, W., U. S. Patent 494,586, Apr. 4, 1893; Potter, H. M., U. S. Patent 875,284, Dec. 31, 1907; Fulton, C. H., and Coursen, W. A., U. S. Patent 1,048,144, Dec. 24, 1912.

advantage of generating heat close to the material to be melted. In another smaller furnace the following results were obtained:

TABLE 20.—*Results on small granular-resistor crucible tilting furnace.*

Heat No.	Time.	Charge.	Material.	Pouring temperature.	Kw. h. used.
	<i>H. m.</i>	<i>Pounds.</i>		<i>° C.</i>	
1.....	1 10	25	Red brass.	1,225	42
2.....	40	25	do.....	1,220	30
3.....	25	25	do.....	1,225	22
4.....	20	28	Copper....	1,150	13½
Total.....	2 35	103	.....	a 1,200	107½

a Average pouring temperature.

After two hours of running, hot spots developed in the resistor, or the crucible failed, or some other mechanical difficulty arose. Unless the crucible is lined or covered with some nonconductor of electricity current is carried by the crucible and its contents. With a loosely packed charge not much current could be carried by the metal in the crucible, so that the current in the furnace, even with a conducting crucible, might not be excessive, but when the metal was melted, unless the nonconducting layer was perfect, the current was short-circuited through the center of the furnace by the charge itself. The main heating was done between crucible and electrodes rather than in the body of the resistor, an arrangement which soon caused hot spots to develop, with resultant burning out of the crucible. When a crucible breaks in such a furnace, it has to be cooled, torn down, and refilled with resistor.

Very small tilting brass furnaces of this type, holding 5 or 10 pounds of metal and using a crucible lined with alundum cement, have been used by the Bureau of Mines, and found useful in such laboratory work as the calibration of pyrometers for use in molten brass and copper up to 1,475° C.

As the size increases the difficulty of maintenance increases disproportionately, and in anything like commercial sizes, run at the necessary temperatures for brass melting, this type becomes impractical.

Various experiments have been made on furnaces of this type. A Baily tilting furnace⁸¹ to hold some 400 pounds of brass was tried out on a laboratory scale and was advertised⁸² for melting brass and aluminum.

It was reported that the National Carbon Co. carried on some experiments on a brass furnace of this type, in the hope of extending the market for resistor carbon. It was also reported in 1913 that the

⁸¹ Data from conversation of Apr. 28, 1913, with R. P. Bicknell, Electric Furnace Co. of America.

⁸² Advertisement, front cover, July, 1913, issue *Electrochem. and Met. Eng.*

General Electric Co. were testing or had designed a furnace of this general type in which the crucible was heated from the bottom, resting on a bed of granular resistor. It is not known whether this design was intended as a tilting or a lift-out furnace. In 1913 also C. E. Bonine attempted to develop a tilting crucible steel furnace for the Hess Steel Castings Co., in which a crucible lined with insulating material was embedded in a granular resistor which used three-phase current. The other furnaces of this type that were tried were probably all single phase. The Bonine furnace was to be applied to brass as well as to steel if successful.

Of all these granular-resistor tilting furnaces only the Baily ever reached the point where it was considered a real possibility for brass melting, and the Baily, in this form, never received commercial test. The work of the Electric Furnace Co. on this form of the Baily furnace gave experience which finally bore fruit in the present commercial form of the Baily furnace, which is like the original only in using a granular resistor and in being a tilting brass furnace.

Nonuniform heating of the resistor, disarrangement of the resistor when the furnace is tilted, necessity for low voltage, high amperage current, poor crucible life, and inability to maintain an electrically insulating coating on the crucible all make it probable that without new refractory materials for crucibles and for insulating coatings of different properties than those now available the crucible furnace with the crucible in direct contact with a granular resistor will prove impractical in commercial sizes and will only be useful in very small sizes for laboratory use.

FOUNDRY TEST OF BAILY TILTING CRUCIBLE FURNACE WITH GRANULAR RESISTOR BELOW CRUCIBLE.

In September, 1914, a Baily tilting furnace built by the Electric Furnace Co. of America was tested at the plant of the Detroit Copper and Brass Rolling Mills. Through the courtesy of the Detroit Copper and Brass Rolling Mills a representative of the Bureau of Mines was permitted to witness the test.

This furnace consisted of a vertical cylinder lined on the bottom and sides with fire brick and having infusorial earth packed between the brick lining and the furnace shell. In the bottom of the cylinder was a horseshoe-shaped resistor trough, rammed up from carborundum fire sand with a water-glass binder, 8 inches wide, 6 inches high, inside, with 2-inch walls. The inner side of the trough was 1 inch away from a 12-inch diameter fire-brick pedestal some 15 inches tall, on top of which rested a shallow dish-shaped crucible with a pouring lip. The crucible was wedged against the furnace walls with brick to hold it in place when the furnace, which was hung on trunnions,

was tilted. The fire-brick roof was dome shaped, coming down within a few inches of the crucible at the outside of the furnace, but leaving space for piling up of the charge in the center. The charging hole was in the center of the roof and closed by a fire-brick cover. The pouring spout of the crucible led into another cut in the furnace wall at front. The spout was plugged with a fire brick. Below this furnace spout was another hole which was also plugged, through which granular resistor (4-mesh chip graphite) could be charged into the resistor trough as it burned away. A third hole below formed a tap hole for drawing off metal should a crucible break.

Two 4 by 4 inch carbon electrodes, carrying flexible leads to allow tilting, entered the back of the furnace and led the single-phase current into the resistor troughs. The 100-kw. transformer had various voltage taps from 80 to 40 volts by 5-volt steps, through which, by a switch, the voltage and hence the power input could be regulated.

The crucible was made of regular fire-clay-graphite mixture, had a capacity of some 700 pounds of metal, and cost, at 1914 prices, \$21.50 each. The shallow, flaring form of the crucible was designed to catch as much heat as possible from the resistor below it by direct radiation and also to allow pouring the metal completely without exceeding the angle of repose of the granular resistor in the open trough below.

Power was thrown onto the cold furnace at 7.15 a. m. At 11.26, when 210 kw. h. had been used, a pyrometer above the empty crucible read $1,160^{\circ}$ C. A charge of 370 pounds of leaded yellow brass and some new copper, lead, and zinc, but mainly scrap brass, was put in at intervals, the last (save the zinc) being charged at 12.20 p. m. The zinc was added at 12.40 p. m., and the metal poured, at about $1,100^{\circ}$ C., at 12.44 p. m., the heat proper having used 112 kw. h. The furnace could not be tilted far enough to drain all the metal from the furnace, and about 100 pounds was retained, the crucible having sunk below its original position on account of the softening and flattening of the fire-brick pedestal. No appreciable zinc fume had been given off during the first heat, but during the pouring vast clouds of it arose through the wedges from the open space between the furnace walls and the crucible. Metal had found its way into the resistor trough. It was supposed that this metal had leaked down between the crucible spout and the furnace spout, the fire-clay luting of this joint having been broken away by the settling of the crucible as the pedestal flattened.

A second 370-pound charge was started at 12.54 p. m., and an attempt at pouring it made at 1.45. The clouds of zinc oxide rolling out of the furnace during this heat had indicated that there was a good

deal of metal down in the resistor, and the current had to be shut off at 1.25 p. m., only 41 kw. h. having been supplied to the furnace on the second heat, the melting of the last 20 minutes before attempting to pour being done by stored heat.

Only about 100 pounds could be poured from the crucible. A tap hole in the bottom of the furnace designed to drain off metal in case of crucible breakage was opened, and some 100 pounds drained from the furnace bottom.

On raising the roof and examining the furnace it was found that the fire-brick pedestal had softened and flattened and the crucible had cracked between its center, which had of course sunk down with the pedestal, and the projecting lip held in the furnace spout. Metal had then dripped down from the crack into the resistor below. The rear wedge between the furnace and wall had been torn away by the dropping of the crucible. The roof brick were dripping somewhat. It is not surprising that the fire-brick pedestal softened. The inner circumference of the resistor, which was in the shape of a horseshoe, was only about $2\frac{1}{2}$ feet, the outer circumference about 4 feet. Naturally the current takes the shorter course and concentrates on the inside of the resistor, next the pedestal. Since the electrical resistance of hot graphite is lower than that of colder graphite, the inner path became progressively easier for the current to follow, and the inner part of the resistor necessarily became hotter and hotter. Fire brick would not stand up at a distance of 1 inch from so hot a resistor.

In a previous test another fire-brick pedestal had been softened in one heat and the crucible slipped down. Had a pedestal of carborundum been used the furnace would probably have stood up long enough to show the efficiency of the design as regards power consumption and metal losses.

The test showed the trouble that would occur whenever a crucible so held above the resistor might break. The crucible itself would have to last 100 heats at the crucible prices then prevailing in order to equal the crucible cost then being obtained in coke fires; the design therefore was abandoned and the Electric Furnace Co. of America turned to the 8-pot crucible lift-out furnace, which had been previously described, and to the design of the early forms of the Baily tilting hearth-type furnace.

WEINTRAUB FURNACE.

As the crucible tilting furnaces of the granular-resistor type have been shown to be impractical, it remains to discuss other forms. Laboratory furnaces of the wire-wound resistor type using platinum or nickel-chromium resistors and commercial furnaces using such

resistors, as the General Electric furnace for heat treatment of forgings for big guns,⁸² if supplied a constant-voltage current, draw less and less current as the resistor heats up, and utilize less power. Most metals become poorer conductors of electricity as they become heated. To maintain the power supply, the voltage has to be progressively raised. Carbon and graphite, on the other hand, become better conductors, as they heat up; at a constant-voltage supply they draw progressively more current and power. Either type of resistor, then, requires some system of voltage control. Metallic silicon, however, increases in resistance with increase in temperature,⁸⁴ while graphite decreases in resistance. By using a combination of silicon and graphite as a resistor it should be possible to construct a furnace which would require less regulation than most resistance furnaces. Silicon also has the desirable property of acquiring a thin oxide coating in air at high temperature and thereafter not oxidizing rapidly.

Weintraub⁸⁵ designed a crucible tilting furnace to use a cage or grid of silicon, silicon-coated tungsten rods, or silicon-coated graphite rods as resistors, similar to the carbon-rod resistor of Greenwood and Hutton, previously described. A tilting crucible brass furnace using this resistor and holding 125 pounds of metal was constructed at the Lynn works of the General Electric Co. and was reported to show an acceptable figure as to power consumption. The resistor was said to be capable of running steadily at 1,300° C.

Silicon-coated, tungsten-cored rods were not practicable, as they became brittle, evidently from a combination of the tungsten and silicon. Plain silicon rods were tried and could be operated by using a transformer with two taps, one to give the starting voltage, the other the operating voltage.

Graphite rods coated with silicon were made, however, and the current passing through the graphite heated the silicon, starting from the cold; by properly proportioning the core and the coating the resistance was so uniform at different temperatures that only 5 per cent external resistance or 5 per cent voltage regulation was required. The problem of making electrical connection to the silica-coated surface of the silicon was solved (1) by making the elements of the resistor in U or hairpin form, thus halving the number of contacts; (2) by inserting the end of the in a nickel cap filled with a molten alloy of 90 per cent silicon and 10 per cent aluminum, and letting the alloy solidify; (3) by making the con-

⁸² See Johnson, I. F., How the power house aids the forge: *Iron Trade Rev.*, vol. 1919, p. 1223.

⁸³ See Anonymous, Silicon for resistor material: *Elec. World*, vol. 55, 1910, p. 409.

⁸⁴ See Weintraub, E., U. S. Patents 1,118,387, Nov. 24, 1914; and 1,134,788, Apr. 6, 1915.

nection through the nickel. The resistor does not change in the course of time, and in small sizes its elements, though rather fragile, could be made fairly strong and tough as compared to the usual brittleness of silicon. Further development would have to be made, according to Dr. Weintraub,^{85a} before a furnace using such a resistor could become a commercial success.

Silicon, unfortunately, melts at about 1,420° C.; even 1,400° C. is a low temperature for the source of heat when a material is to be heated by radiation from the resistor to 1,250° or 1,300° C., as in gun metal or red brass to be poured into very light castings. As Northrup⁸⁶ points out, the efficiency of a resistor running at 1,300° C. is zero for melting a material to be brought to 1,300° C.; other things being equal, the greater the difference in temperature between the source of heat and the material to be heated the greater is the efficiency to be expected, and, conversely, the lower the difference the lower the efficiency.

In crucible resistor furnaces for brass in general the interior of carbon resistors probably runs at much nearer 2,000° C. than 1,300° C. Besides the disadvantage of a low melting point, silicon has another—its brittleness. Casting a large grid in one piece as a resistor would probably be impracticable, and the problem of making stable electrical connections between the parts of a built-up grid would also be difficult. The grid is a desirable form for such a resistor, as it offers great radiating surface, and hence can be run with less danger of melting the inside than could a more massive form.

The silicon-coated graphite resistor should serve for use in a furnace to melt aluminum, possibly yellow brass, and other lower melting alloys, but its limitations as to temperature and its fragility make it of little promise for general use in brass furnaces. No other development of this idea is known.

CRUCIBLE TILTING FURNACES WITH SOLID OR MOLDED RESISTORS.

FOUNDRY TEST OF HELBERGER FURNACE.

One of the early trials of an electric furnace in a brass foundry was that of the Helberger at the works of the National Cash Register Co., at Dayton, Ohio, in January and February, 1914. Through the kindness of this firm a representative of the bureau attended the

^{85a} Weintraub, E., Personal communication, Jan. 12, 1920.

⁸⁶ Northrup, E. F., Production of high temperature and its measurement: *Met. Chem. Eng.*, vol. 17, 1917, p. 685.

earlier part of the test. The Helberger furnace,⁸⁷ which Japing and Krause⁸⁸ say has been in use in German brass foundries, is a furnace with a tall, cylindrical, carbon resistor, held by pressure between a lower carbon plate and an upper carbon ring, serving as electrodes, and surrounded by refractory walls.

A tall, narrow crucible made of material of fairly low electrical conductivity, but resembling the ordinary crucible material, slips snugly inside the carbon resistor. A pouring spout made of per-

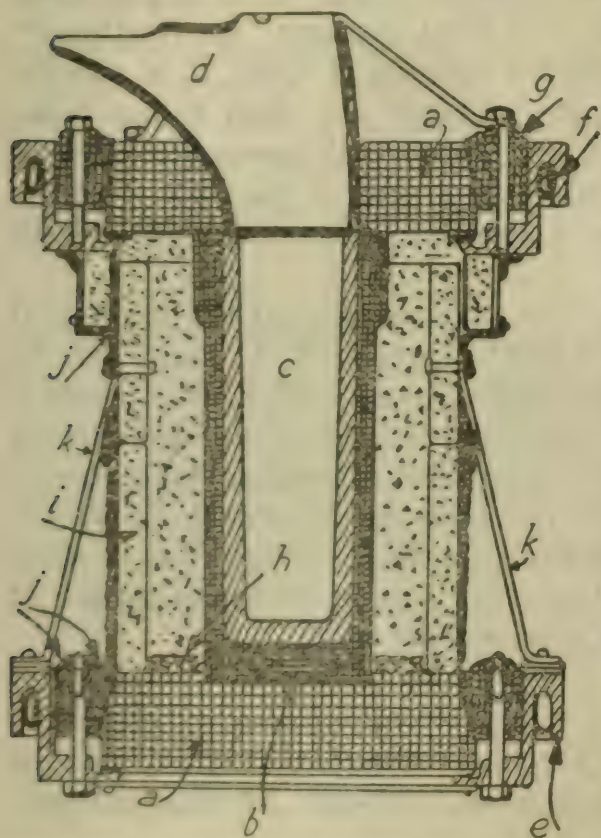


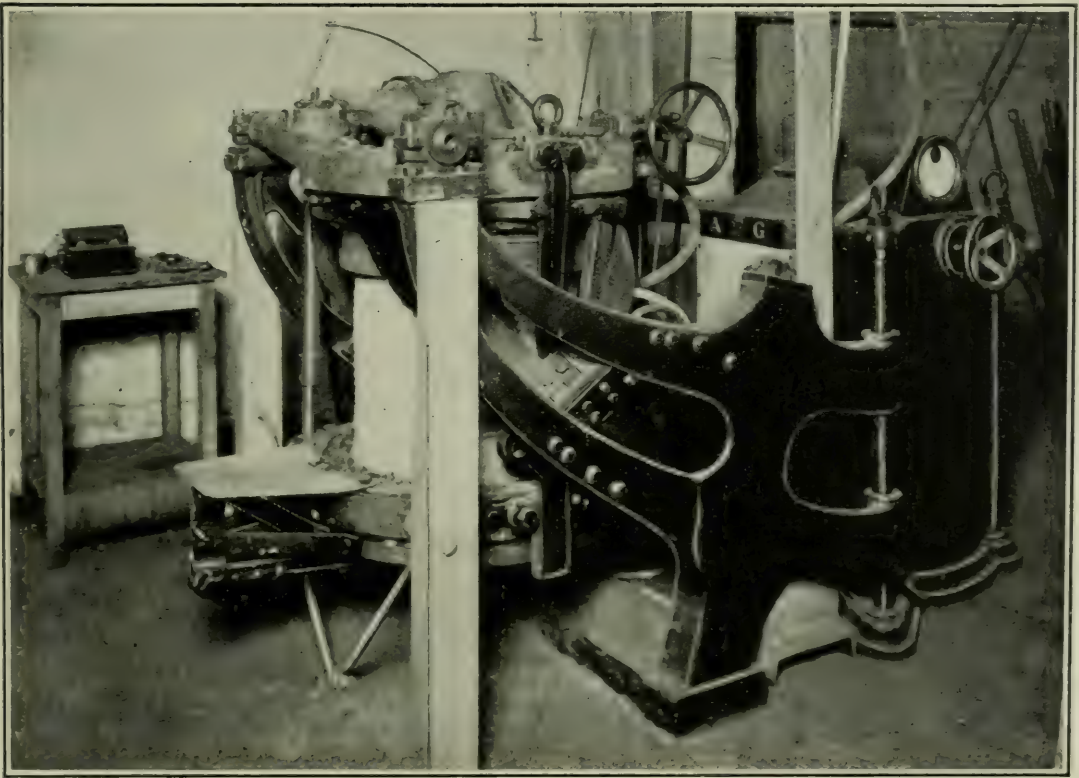
FIGURE 7. Diagram of Helberger furnace: *a*, electrodes; *b*, resistor; *c*, crucible; *d*, pouring spout; *e*, cast-iron ring; *f*, water chamber for cooling; *g*, wedge, graphite or cast iron; *h*, granular magnesite; *i*, fire-clay cylinder; *j*, asbestos rope; *k*, brass.

forated sheet iron coated with crucible material fits inside the upper electrode and joins onto the crucible, the joint being luted up. A heavy current is passed through the carbon resistor at a low voltage—between 4,000 and 8,000 amperes at from $6\frac{1}{2}$ to $11\frac{1}{2}$ volts. To avoid losses of lead in carrying so heavy a current, the 440-volt, 100-kw. variable-voltage transformer is made an integral part of the furnace, and no flexible secondary leads are provided, but very large laminated copper contacts or brushes under pressure allow breaking the circuit when the furnace is tilted. The furnace tilts about the lip.

The pressure between the electrodes is regulated by a handwheel, which actuates three screws, each one of which can also be independently regulated to obtain uniform pressure around the circumference.

⁸⁷ See Helberger, H., U. S. Patents 558,357, Apr. 14, 1896; 769,250, Sept. 6, 1904; 932,986, Aug. 31, 1909; and 1,023,309, Feb. 20, 1912; Anonymous, The Helberger furnace: *Metal Ind.*, vol. 9, 1911, p. 212; Anonymous, Electric transformer crucible furnace: *Met. Chem. Eng.*, vol. 10, 1912, p. 501; Helberger, H., German Patents 228,918 of Jan. 14, 1908, class 21b, group 11; 235,486 of Dec. 9, 1910; 246,083 of Sept. 2, 1910; Anonymous, *Brass World*, vol. 7, 1911, p. 79; Anonymous, *Metal Ind.*, vol. 9, 1911, p. 212; Harden, J., The Paragon electric furnace and recent developments in metallurgy: *Trans. Faraday Soc.*, vol. 7, 1912, p. 183; von Schwarz, M., *Int. Zeit. Metallog.*, vol. 2, 1912, p. 258; Perkins, F. C., German crucible electric furnace: *Chem. Eng.*, vol. 18, 1913, p. 97.

⁸⁸ Japing, E., and Krause, H., *Kupfer und Messing*: 1912, p. 93.



HELBERGER CRUCIBLE TILTING FURNACE.



POURING METAL FROM HELBERGER FURNACE.

The furnace appears to have been used in Germany in very small sizes for such purposes as jewelers' use. The makers of this furnace, the German Allegemeine Electricitats Gesellschaft, advertised it in a 100-kg. (220-pound) capacity. The National Cash Register Co. ordered one in August, 1912, and when it was received a year and a half later no tilting device was supplied with it. A counterbalanced tilting device was designed and installed by the National Cash Register Co. The furnace and transformer together weighed 9,000 pounds, though its capacity was but about 200 pounds, and cost \$6,000 without the tilting device.

It is very likely that the furnace, though listed in this size, had not hitherto been made in as large a size and was built to fill the order of the National Cash Register Co. The furnace is illustrated in figure 7 and Plates IV and V. The test at the National Cash Register Co. has been fully described by Dorsey.⁸⁹

The first German crucible failed after six heats; the crucible was perforated and the metal ran down between crucible and resistor. The next crucible lasted 21 heats, during which the following figures were obtained on red brass; the furnace, having been operated until quitting time the previous day, was warm on the morning of the test.

TABLE 21.—*Test of Helberger furnace on Feb. 4, 1914.*

Heat No.	Time.	Amount of metal.	Temperature.	Kw. h.	Kw. h. per 100 pounds, average.
	<i>H. m.</i>	<i>Pounds.</i>	<i>° C.</i>		
15.....	2 23	150	1,200	120	.....
16.....	49	150	1,270	55	.....
17.....	40	150	1,200	51	.....
18.....	30	150	1,200	39	.....
19.....	32	150	1,200	50	.....
20.....	30	180	1,270	42	.....
21.....	42	165	1,200	40	.....
22.....	34	150	1,270	55	.....
23.....	31	150	1,200	50	.....
24.....	36	150	1,200	48	35.6
Total.....	7 47	1,545	.....	550	.....

After four more heats the crucible failed, and the resistor and upper electrode also had to be replaced.

A new crucible, new resistor, and new top plate, all from the makers, were installed and 18 successive heats were made, the furnace having been brought up to running temperature by heating it empty on the afternoon of February 22, 1914.

⁸⁹ Dorsey, H. G., Tests on electric furnaces for brass foundries: Trans. Am. Inst. Metals, vol. 8, 1914, p. 246.

TABLE 22.—Further tests of Helberger furnace on February 23 and 24, 1914.

Heat No.	Time.		Amount of metal.	Temperature.	Kw. h.	Kw. h. per 100 pounds, day average.
	H.	m.	Pounds.	° C.		
32.....	2	39	150	1,175	139	.....
33.....		40	150	1,200	67	.....
34.....		32	150	1,175	56	.....
35.....		41	150	1,175	50	.....
36.....		30	150	1,200	46	.....
37.....	1	33	150	1,175	44	.....
38.....		44	175	1,175	80	.....
39.....		22	150	1,240	51	.....
40.....		20	150	1,200	38	41.5
Total.....	8	1	1,375	.....	571	.....
41.....	2	34	150	1,175	175	.....
42.....		40	150	1,200	67	.....
43.....		32	155	1,175	62	.....
44.....		30	150	1,240	60	.....
45.....		31	150	1,175	33	.....
46.....	1	10	150	1,175	28	.....
47.....		37	170	1,240	72	.....
48.....		32	170	1,175	51	.....
49.....		30	156	1,200	45	42.2
Total.....	7	36	1,401	.....	593	.....

After these 18 heats the third crucible wore out. The average of the three all-day runs was 1,440 pounds melted in 7½ hours, using 571 kw. h., or 800 kw. h. per ton. On 24-hour operation the furnace would melt at about 600 kw. h. per ton. The average life on three crucibles was 15 heats. As no more German crucibles were at hand, attempts were made to ram up a lining to the resistor of carborundum fire clay; a maximum of six heats was thus obtained. The pouring spout was flimsy, became badly damaged during the test, and required frequent patching.

There was no convenient way to close the top of the furnace tightly to prevent volatilization and oxidation, so a layer of charcoal was put on after the metal had melted. The crucible was so tall and narrow—7 inches in diameter by 25 inches high (not including the pouring spout or hood)—that it would hold but little bulky scrap, and the operator had to stand on the little step in front of the crucible and feed in the charge continually.

Only one determination on metal lost in melting was made, this being on one of the earliest heats. Two hundred pounds (75 per cent gates, 25 per cent new metal) of an alloy of 89 per cent copper, 3 per cent zinc, 5 per cent tin, and 3 per cent lead was charged and 199 pounds of ingot was poured, a metal loss of 0.50 per cent.

The low crucible life and the great amount of attention demanded from the operator in charging, which would require one man per furnace, caused the furnace to be discarded by the National Cash Register Co. When a crucible failed during a heat and metal ran

down between crucible and resistor, it picked up metallic silicon and aluminum reduced (in the presence of another metal to collect the aluminum) by the carbon of the resistor from the fire-clay bond of the crucible. If any of this metal contaminated with silicon and aluminum poured out with bulk of the charge or diffused back into the main charge, the metal was ruined for the purposes of the National Cash Register Co.

A smaller Helberger furnace was tried out at the New York assay office in 1913 for melting precious metals, but gave a great deal of trouble and was discarded.

An 80-kw. Helberger was tried out for melting steel about the same time by the Hess Steel Castings Co., of Bridgeton, N. J., and is reported to have given much trouble and to have been discarded also. All in all, the Helberger furnace was complex and costly and seems to be quite impracticable for use under American foundry conditions.

ELECTRO-METALS EXPERIMENTAL FURNACE.

Electro-Metals, Ltd., of London, England, according to Boving,⁹⁰ experimented with a brass furnace in which the crucible, made to have high electrical resistance, is used as the resistor. The furnace gave trouble, especially in the contacts between crucible and the upper and lower electrodes, so that no real success was achieved.

MORGAN FURNACE.

The Morgan Crucible Co., of Battersea, London, has advertised "Morgan's patent electrically heated crucible," which is used both as resistor and metal container. This is designed in two styles,⁹¹ one very much like the Helberger, with a crucible held between water-cooled upper and lower electrodes, which serves as resistor and metal container as well, being coated inside with an electrically nonconducting coating. It is said that fine adjustment of the resistance is obtained by varying the pressure between the resistor and the terminals. It would appear to be a very dangerous procedure to lighten this pressure enough to alter the resistance, thus obtaining a contact with an appreciable drop in voltage absorbing power, and causing local heating at the contacts. The vertical tilting crucible type is designed in two sizes, one to hold 20 pounds and one to hold 150 to 200 pounds of brass.

⁹⁰ Boving, J. O., Letter of July 3, 1918, to the director of the Bureau of Mines.

⁹¹ Anonymous, Electric furnace developments for nonferrous metals: *Metal Ind.* (London), vol. 14, 1919, p. 444; *Metal Ind.* (N. Y.), vol. 19, 1919, p. 424; Speirs, C. W., British Patents, 24,626 of 1912, 162,246 of Oct. 7, 1919; U. S. Patents 1,335,079, Mar. 30, 1920; and 1,366,135, Jan. 18, 1921; Discussion: *Jour. Inst. Metals* (British), vol. 17, 1917, p. 277; compare von Zeerleder, A., U. S. Patent 1,367,442. Compare also Soucni, C., U. S. Patent 1,375,615, Mar. 3, 1921.

A drain spout in the bottom of the refractory inclosure about the resistor crucible acts as a safety outlet in failure of the crucible. In view of the short life of such a crucible, indicated by the Helberger test, this outlet seems a necessary provision.

In larger sizes the furnace has a shallow trough (fig. 8) for single-phase current, or a dish for three-phase (fig. 9), provided, respectively, with lugs at two or three points, by which pressure contact is made with the water-cooled terminals. A spout is molded in the trough or dish for pouring. The trough or dish which forms the resistor of the tilting furnace is lined with an electrically non-conducting layer, within which the metal rests. The Morgan Crucible Co. advertised to supply this type in any size up to a capacity of 1 ton of copper or brass. It is claimed that on the second heat of a day 800 pounds of 65:35 brass is melted in two hours with 120 kw. h., or at the rate of 300 kw. h. per ton, and that in regular operation (it is

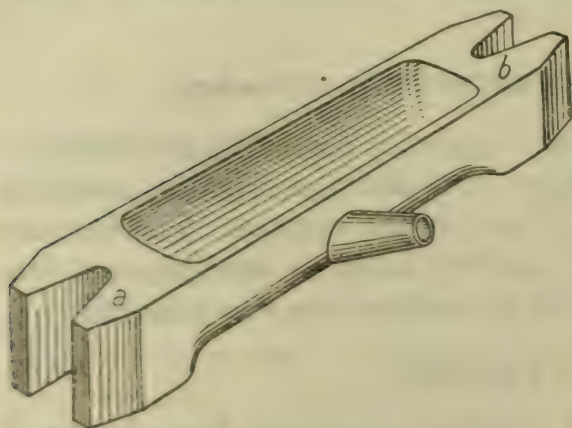


FIGURE 8.—Detail of Morgan furnace' design, single phase.

not specified whether on a 9 or 10 or a 24 hour basis) the power consumption averages 300 kw. h. per ton. It is said that 1,300° C. is the limit to which metal can be safely heated in the furnace.

The crucible is said to be completely protected from mechanical damage and thus the life is long, but no figures on the actual life are given.

Such a resistor-crucible furnace would be thermally efficient while the resistor lasted, as the heat is generated so close to the metal. The resistor would take a low voltage and a high amperage and would involve large heat losses in the water-cooled terminals. Its reliability would depend on two factors—the uniformity of the molded fire-clay (or similar bond) graphite resistor and the impregnability of the electrically nonconducting lining.

If the resistor is not uniform, so that local heating gets started at any point, a hot spot will surely develop and failure ensue by melting or vaporizing the bond, since a graphite resistor will continue to heat up progressively in any spot that becomes locally overheated, due to the fall in resistance as the material heats up. This fall in resistance in any spot offers an easier path to the current, which tends to concentrate in the hot spot, heating it up still more, and the vicious circle goes on till a temperature is reached at which the material fails.

Impregnability of the electrically nonconducting lining is close to impossible to attain with material now available. If the current in

the single-phase trough shown in figure 8 fails to pass through the walls of the trough about the cavity for holding metal and by reason of a crack in the insulating lining at both ends follows the path of lowest resistance through the molten metal in the trough, the voltage drop through the metal would be small compared to the total, and practically all of the resistance would be at the ends *a* and *b*. When this occurs, unless the rise in amperage is at once noted, the charge poured immediately (if it is hot enough to pour), the furnace cooled, and the insulating lining patched or replaced, practically all the power will be absorbed in the ends *a* and *b* and the temperature must rise till the ends of the resistor fail. If the increase in current on failure of the insulating lining is prevented by fuses or circuit breakers, so that there is no further heating, it is likely that the charge may be too cold to pour and must be left to freeze in place, with every chance of its removal ruining the resistor.

There are few materials, even though good electrical insulators at low temperatures, which do not become more or less conducting at 1,000° to 1,300° C., the temperatures of a brass furnace. One of the best high temperature insulators for electricity is alumina, and alundum cement is the best material for use as the insulating coating.

This coating would have to be thick enough that its resistance is much higher than that of the resistor trough, or the current would divide, part passing through the resistor and part, from *a* through the coating into the molten metal, out through the coating at the other end, into *b*.

If even two small cracks should allow the metal to reach the resistor, short-circuiting would begin. When it is considered that the

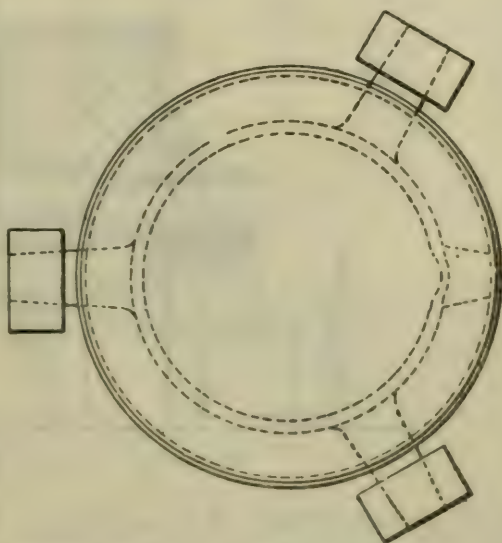
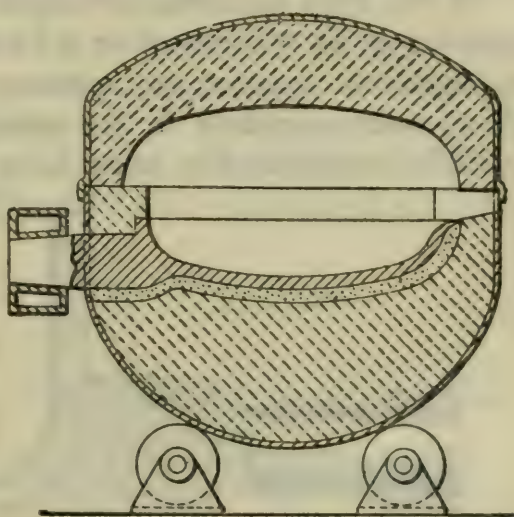


FIGURE 9.—Detail of Morgan furnace, three phase.

coefficients of expansion of the coating and of the resistor may not be and probably are not the same, it is obvious that thermal expansion would itself tend to crack the coating. Added to this danger is that of cracking the coating when a heavy ingot is dropped accidentally into the trough.

If this type has been developed to the extent that the resistor and coating in an 800-pound or a 1-ton furnace show a life long enough to make the type of any commercial value, unusual judgment must have been exercised in the selection of materials, and supremely skillful workmanship must have been used in molding the resistor

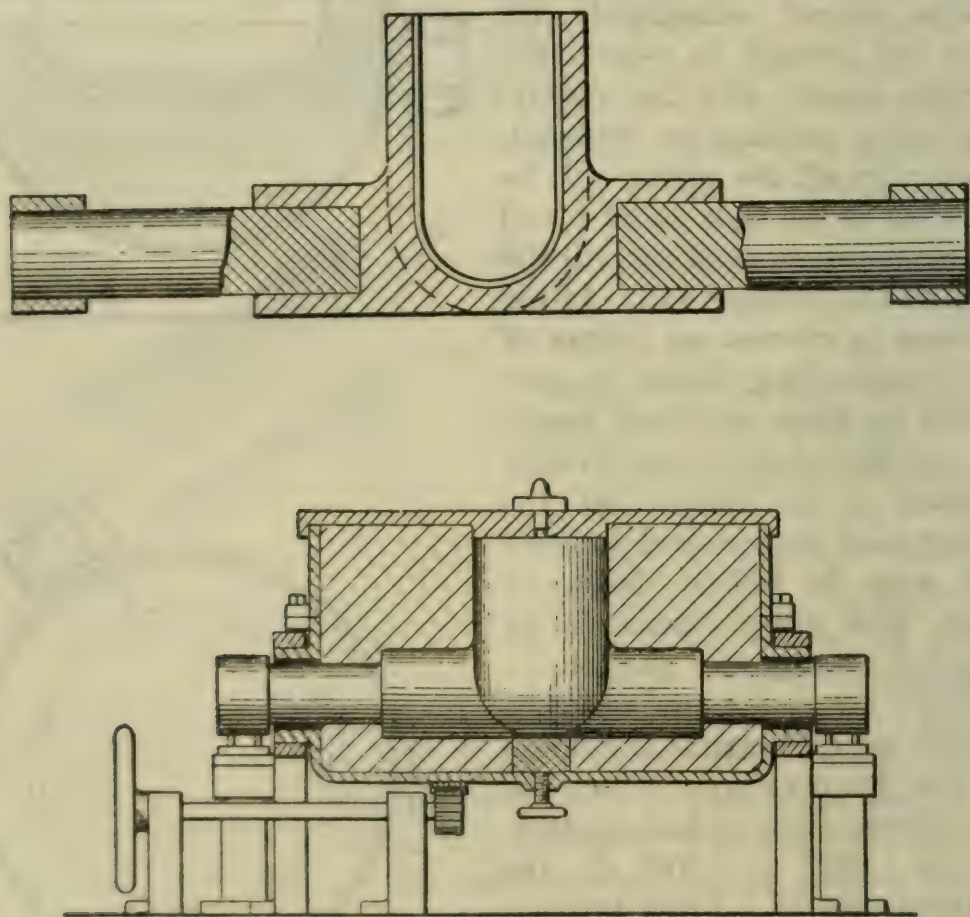


FIGURE 10.—Conley crucible tilting furnace.

and in applying the coating. No final conclusions on this type can be drawn until it has been operated under foundry conditions. Although the furnace was advertised as ready for use a couple of years ago on foundry test has yet been recorded, and the advertisements have not appeared in late issues of the periodicals formerly carrying them.

CONLEY FURNACE.

The Conley⁹² furnace is another resistor furnace (see fig. 10) in which the metal is contained in a crucible integral with the resistor,

⁹²Conley, M. R., U. S. Patents 769,250, Sept. 6, 1904 (application filed Oct. 1, 1902), 989,568, Apr. 18, 1911, and 1,023,996, Apr. 23, 1912.

and a lining of electrically nonconducting material is provided. The furnace is arranged to tilt for pouring. Experiments are said to have been made as early as 1897.⁹³ In 1910 this furnace was tested at the Electrical Testing Laboratories, New York, and was demonstrated to representatives from rolling mills and foundries. The foundrymen did not consider it suitable for practical foundry use.

Some figures on the 1910 tests were submitted by Florence and Hampton, who control the Conley patents. According to these figures the furnace, which had a capacity of 50 to 70 pounds, ran at 14 to 22 volts, taking 300 to 400 amperes when started cold and 1,200 to 1,300 amperes when fully hot. The data are summarized in Table 23.

TABLE 23.—1910 tests on experimental Conley furnace.

Heat No.	Probable state of furnace at start.	Amount charged.	Time.	Kw. h. used.	Time per 100 pounds.	Kw. h. per 100 pounds.	Kw. h. per ton.
		<i>Pounds.</i>	<i>Min.</i>		<i>Min.</i>		
1.....	Cold.....	50	55	17.41	110	34.8	696
2.....	Hot.....	50	23	8.65	46	17.3	346
3.....	Cold.....	68½	75	20.82	110	31.6	632
4.....	Hot.....	68½	39	15.62	57	22.8	456
5.....	Cold.....	70	70	20.44	100	30.0	600
6.....	Hot.....	55	55	17.67	100	32.2	644
7.....	do.....	72	56	17.41	78	31.2	624
8.....	do.....	^a 20	25	4.81	125	24.0	480
9.....	Cold.....	45	50	19.13	111	38.3	766
10.....	do.....	53	53	(b)	100	.....	.....
11.....	Hot.....	51	30	(b)	59	.....	.....
12.....	Cold.....	50	90	21.5	180	43.0	860
13.....	Hot.....	52	60	17.3	116	28.9	598
14.....	do.....	100	70	24.3	70	24.3	486
15.....	do.....	35	40	10.34	114	25.9	518
Total.....	.....	840	.....	215.40	.....	.....	.....

^a This charge consisted of scrap copper and some scrap brass. All the other charges consisted of copper only.

^b Not given.

In a report from another source the 70-pound furnace is said to have melted two heats of 2:1 brass, the first heat taking 37 minutes (temperature of furnace at start not stated) and the second 27 minutes. The metal loss was said to be 0.15 per cent and the power consumption at the rate of 363 kw. h. per ton, no statement being made as to whether this refers to the second heat only or to both. No figures are given on life of the resistor crucible on the 70-pound size.

The resistor crucible of a furnace of 20 pounds capacity is said to have lasted 45 heats.

Miller^{93a} quotes the inventor of the furnace as claiming that this type can be built up to 1,200-pounds capacity, capable of melting copper at 240 kw. h. per ton, and giving a metal loss (alloy not

⁹³ Electric-furnace development for metals: Metal Ind., vol. 17, 1919, p. 927.

^{93a} Miller, D. D., The electric furnace as a medium for heating nonferrous metals; Jour. Am. Inst. Metals, vol. 11, 1917, p. 275.

stated) of less than 0.20 per cent. There was a report in 1917 that the furnace was to be developed for use in an American plant producing shrapnel disks on a French order, but no installation of it is known. It is quite certain that the furnace was never actually built in a 1,200-pound size.

The comments made on the Morgan furnace apply also to the Conley.

GUTHRIE AND KARCH FURNACE.

Guthrie and Karch⁹⁴ patented a similar tilting furnace. In one form, instead of a solid resistor forming the crucible, each electrode was so shaped as to half inclose a separate crucible, granular carbon being placed between the electrodes and the crucible. Arcs were to be run between the electrodes and the granular carbon, and the heat was thus to be generated by a combination of both arc and resistance.

No actual construction of such a furnace is known, nor was it suggested especially for brass. The crucible life in such a furnace would probably be extremely short.

BARIO FURNACE.

Still another furnace of this general type, made by the Bario Metal Corp., has been advertised. The Bario furnace consists merely of a carbon electrode in which a trough is gouged out to contain metal. The electrode is held in water-cooled terminals, and an extremely heavy current is passed through the electrode, which serves as a solid resistor. No attempt is made at putting an insulating coating inside the trough. The resistor is in the open air.⁹⁵ The furnace is said to have a capacity of 1 to 20 pounds. The electrode, resistor, or crucible, whichever it be termed, is said to last 25 to 50 heats.

In another form⁹⁶ the resistor is placed inside a furnace chamber and radiates heat onto an ordinary crucible placed below it, thus forming a laboratory type of crucible lift-out furnace.

The first form was priced, in January, 1918, at \$1,200, the second form at \$1,400 (list prices), both complete with variable-voltage transformers.

This firm advertises to build electric furnaces to contain from 1 pound to 3 gross tons of metal. No description of the larger furnaces is given in the advertisements, but from correspondence with the makers it appears that arc furnaces are planned for the larger sizes.

Such a furnace might find limited application for some types of laboratory use, and forms somewhat similar in the principle of the

⁹⁴ Guthrie, B., and Karch, J. P., U. S. Patents 979,663, Dec. 27, 1910; and 1,086,164, Feb. 3, 1914.

⁹⁵ De Miles, P., U. S. Patent 1,317,863, Oct. 7, 1919.

⁹⁶ De Miles, P., U. S. Patent 1,317,864, Oct. 7, 1919.

resistor are patented by Pfanstiehl⁹⁷ and Bristol and Johnson⁹⁸ as a laboratory device for the commercial melting of very small quantities of precious metals or raw materials.

These devices are, of course, applicable only to small-scale or laboratory work and have no bearing on the problem of commercial brass melting.

Fitzgerald and Moyer⁹⁹ have described a laboratory furnace which can be used to heat a crucible by radiation from an arc over it or to heat one embedded in granular carbon.

REED FURNACE.

Reed¹ has devised a crucible tilting furnace primarily designed for steel melting, in which is used a carbon resistor grid similar to the Greenwood and Hutton resistor previously mentioned, but instead of radiating heat to the crucible through an air space, as in the Greenwood and Hutton furnace, and leaving the resistor open to oxidation by air, the space between resistor and crucible is filled with molten glass; the composition of the glass is chosen to give the correct fluidity for the temperature to which the contents of the crucible are to be heated. The glass covers the resistor, prevents oxidation, and also conveys heat from resistor to crucible by conduction.

The crucible rests on a slotted pedestal and is held in place at the top of a refractory cap, which also serves to retain the glass when the furnace is tilted to pour.

The furnace is in the early stages of experimental development and no data have yet been obtained on its power consumption, crucible life, and resistor life under operating conditions. It is claimed that the furnace can be shut down, the glass allowed to freeze, and the furnace be started up again without damage to the resistor; that the resistor, crucible, and refractory container for the glass are not attacked by the glass, and that the electrical resistance of suitable glass is so high that the current flows only through the resistor.

The furnace is not primarily designed for brass melting, but if the claims of the inventor are substantiated by actual test it might be adapted for such use. No active development work is being done on this furnace at present, but such development is planned for the near future both on steel and brass.

⁹⁷ Pfanstiehl, C. A., U. S. Patent 1,283,285, Oct. 29, 1918.

⁹⁸ Bristol, W. H., and Johnson, M. J., U. S. Patent 1,323,576, Dec. 2, 1919.

⁹⁹ Fitzgerald, F. A. J., and Moyer, G. C., Electric furnace for experimental work: *Trans. Am. Electrochem. Soc.*, vol. 36, 1919 (not yet published); *Chem. and Met. Eng.*, vol. 21, 1919, p. 769.

¹ Reed, R. R., U. S. Patent 1,357,901, Nov. 2, 1920.

NORTHROP FURNACE

There is one furnace which can be made in a crucible lift-out form as well as in tilting form which is in successful commercial use. This is of an entirely different type from furnaces previously considered, as it uses high-frequency current and is a form of induction furnace, the heat being generated in the metal itself or in the crucible containing the metal and not outside the crucible. This exception, therefore, will be described under induction furnaces.

HEARTH FURNACES USING NO CRUCIBLES.

GENERAL CONSIDERATIONS.

Out of all the many types, forms, and sizes of electric crucible lift-out and crucible tilting furnaces suggested and of the fairly large number tried in the laboratory or in the foundry none has had or offers any real degree of commercial success, with the exception of the one radically different type, the Ajax-Northrup, which will be described later.

The faults of the crucible furnaces in general are small capacity, consequent high labor cost, low production, expense for crucibles, lack of reliability due to fragility of crucibles and insulating linings, and low thermal efficiency, which means a high cost for electric power. All the usual crucible furnaces of the lift-out type use too much electrical energy per ton. Furnaces of the tilting type—with a resistor forming or in contact with the crucible—that might give better results as to amount of energy used per ton, are as a class unreliable because of the inevitably short life of the resistor crucible or insulating lining.

The advantages of crucible furnaces lie in the production of crucible-quality metal and in reducing the metal losses. As these advantages can be obtained in the hearth-type electric furnace without the disadvantages of the crucible type, the obvious next step is to turn to the types that do not use crucibles and that hold the metal in a hearth, discharging it by tilting or tapping.

Vickers² argues against the use of a hearth furnace made of "silicious materials such as bricks, carborundum, etc., which form chemical compounds with the constituents of some alloys, to their great detriment." He does not elaborate the exact cases to which he has reference. Such cases doubtless exist, and there is good reason to consider, in choosing a hearth lining, whether or not it may injure the metal; but the fact that all the electric brass furnaces that are in successful commercial use are of the hearth type is sufficient proof that for many alloys, at least, hearth materials can be found which are

²Vickers, C., *The electric furnace as a copper-melting medium*: Foundry, vol. 45, 1917, p. 280.

not detrimental to those alloys. It is important, however, to make sure that the design of the furnace is not such as to allow the reduction of metallic silicon and its introduction into the bath of brass.

FUNDAMENTAL FEATURES IN THE DESIGN OF USEFUL HEARTH-TYPE FURNACES.

In considering the design of hearth-type electric furnaces for commercial use there are several factors to be considered. Rodenhauser³ has attempted to set forth the requirements of an ideal furnace for melting and refining steel and to show that these are best filled by an induction furnace. Commercial practice has not borne out his argument, as induction furnaces for steel are rarities in the United States, but it is useful nevertheless to follow Rodenhauser's example in pointing out some fundamental requirements of an electric furnace for brass, remembering always that the ideal furnace for one set of melting conditions is not necessarily perfect for another set. These fundamental requirements may be discussed under the topics, metallurgical fitness, reliability, rate of production, thermal efficiency, and electrical characteristics.

METALLURGICAL FITNESS FOR THE WORK.

The prime requisite of a furnace is metallurgical fitness for the work to be done. Unless the quality and uniformity of product desired can be obtained the furnace is of no use. If ladle pouring will not give a satisfactory product, for example, the furnace must be capable of pouring the metal direct into molds. If a given type of furnace will not operate on a given alloy without causing too great metal losses, as a direct-arc furnace on yellow brass, it is barred from consideration unless some abnormal condition makes this loss acceptable on account of a greater saving.

For melting a variety of alloys no furnace can be used from which one charge can not be removed completely enough to prevent injurious contamination of a charge of a widely dissimilar alloy to follow. Versatility, or the ability to melt all the alloys handled by a plant, is a desirable feature of a furnace, and where the output of a plant will not allow the allocation of separate furnaces to separate types of alloys, this feature may become a necessity. Another sort of versatility that is desirable in a furnace is the ability to work economically on either 8, 16, or 24 hour operation per day.

If close temperature limits must be held lest the product suffer, a furnace incapable of close, prompt, temperature control would be either useless or at a disadvantage.

³ Rodenhauser, W., and Schoenawa, J., translated by vom Baur, C. H., *Electric furnaces in the iron and steel industry*, 1917 ed., p. 66.

RELIABILITY.

The furnace must be reliable and must stand up to its work day after day. St. John,⁴ in discussing this subject, has well expressed the situation when he says: "Sustained mediocrity is preferable to intermittent perfection."

Ruggedness is an essential. Reliability is to be attained by rugged construction, by the use of high-grade and suitably chosen refractories, and by the avoidance of complicated construction of heated parts. One can determine with a reasonable degree of accuracy the behavior as to power consumption and as to metal losses of a given furnace type by laboratory tests on a furnace of comparatively flimsy construction; but none but a robustly built furnace, can stand up under constant use in rapid production in foundry conditions.

It is not vital to successful operation that all the appurtenances of an electric furnace be of simple construction or foolproof if they are not placed where they become hot, but are placed where they can be attended to. The more simple and foolproof they can be made the better, of course, but electric furnaces can operate profitably with complicated and delicate appurtenances, as is proven by the operation, for many years, before more simple and less delicate controls were devised, of steel furnaces with complicated electrode-regulating mechanisms that had to be protected by glass cases and that required the almost constant attention of a high-class electrician.

But when delicate or "fussy" construction is attempted in the heated interior of the furnace results are likely to be disastrous. Complicated, fragile resistors, projections in the refractory lining, or anything in the heated zone that can not be readily replaced while the furnace is hot are highly detrimental to reliability. Simplicity and durability of construction inside the furnace are of paramount importance. For example, the tilting furnaces in which a molded fire-clay graphite resistor serves also as crucible or hearth by the interposition of an insulating coating have low reliability, because the coating is almost necessarily fragile, and its failure usually means that of the whole resistor; when that failure occurs the furnace has to be cooled and practically rebuilt.

Similarly, a furnace with a resistor built of a lattice or grid of carbon rods or bars is not likely to be reliable, as the failure of any part of the resistor means a complete shutdown. Arc furnaces have much to commend them, as a broken or damaged electrode can be replaced with but little delay while the furnace is hot.

⁴St. John, H. M. Commercial testing of metallurgical electric furnaces: Chem. and Met. Eng., vol. 21, 1919, p. 378.

The selection of refractories is of utmost importance in attaining reliability. The ideal combination of extreme refractoriness, mechanical strength, great resistance to heat flow, or low thermal conductivity, and cheapness is not attainable in any one refractory. The way to obtain the best results seems to lie in the use of three layers. The inner layer, forming the working chamber of the furnace, should be built of materials chosen primarily for refractoriness, strength, freedom from spalling under changes of temperature, and for ability to withstand such conditions of the furnace as a strongly reducing atmosphere or as contact with a given alloy, when used in the hearth, without being damaged by such contact and without damaging the alloy. Low thermal conductivity and low cost of this layer are secondary to the considerations cited above. The intermediate layer should be of good refractoriness and strength, with the lowest thermal conductivity consistent with these qualities. Cheapness becomes a factor in choosing this layer. The outer layer should be chosen primarily as a heat insulator against the rather low temperature of the outside of the intermediate layer.

Sometimes two layers only prove satisfactory, in which case the outer layer must combine the properties of the intermediate and the outer layers of a three-layer lining.

There are no grave difficulties in obtaining highly satisfactory materials for all but the inner layer, the choice of which is limited by the materials available and represents a balance between initial cost and life. Depending on conditions, it may be cheaper to use expensive materials and to avoid the labor and interest charges and loss of production due to shutting down more frequently for relining or it may be better to use cheaper materials and to reline more often.

RATE OF PRODUCTION.

Next in order of importance comes the rate of production. A high rate of production cuts down overhead, labor, and interest charges and is essential to justify the high initial cost of an electric furnace, as this initial cost is necessarily far above that of a fuel-fired furnace. A high rate may be obtained by a design of high thermal efficiency, but no less by other factors of design. A furnace should be capable of rapid charging and discharging; one that can be charged from overhead, by dumping of the charge into it, or that is capable of mechanical charging in other ways is preferable to one in which slow hand charging, as through a small side door, must be done. If slagging or stirring is necessary on a given charge, the furnace must allow easy access to all parts of the bath for these purposes. Even so small a matter as a difference of half a minute in the speed with which a charging door, pouring spout, or tap hole may be

opened or closed may affect materially the rate of production, since these operations are repeated many times.

THERMAL EFFICIENCY.

A high thermal efficiency in total kw. h. used per ton of product is of importance, because electric energy is a more expensive source of heat than the combustion of fuel. For a given amount of power used a high thermal efficiency also means a higher rate of production.

Thermal efficiency is to be attained in the following ways: (1) By generating the heat in or as near to the charge as possible; (2) by supplying power at the highest practicable rate of power input; (3) by the avoidance of waste space inside the furnace, thus making the furnace compact, with less wall volume to heat and less surface area to radiate heat, and (4) by choosing refractories which will keep the heat inside the furnace instead of allowing it to flow out and be wasted.

The energy supplied does one of two things: It heats the charge or it goes to waste into or through the walls, roofs, doors, and electrodes. If the charge is so placed that it gets the first chance at the heat, taking it directly instead of indirectly after it has first gone to a roof or wall, from which only part of the energy is reflected back to the metal, more will be absorbed by the metal. The energy lost through the walls of a given furnace remains approximately constant for a given operating temperature; if the rate of energy input is increased, not only is the speed of production increased, but the ratio of energy usefully applied to that lost is greater. If a furnace takes 100 kw. and loses 35 kw. through shell radiation and electrode losses, 65 kw. do useful work, and the efficiency is 65 per cent. If the same furnace takes 125 kw. and 37½ are lost, 87½ will do useful work; the output is increased 35 per cent, and the thermal efficiency rises to 70 per cent. Hence the highest rate of power input that the refractories can stand gives the best results as to thermal efficiency and production.

A furnace may not be used continually, but may cool during the night, the walls losing heat, which must be put back during the first heats the next morning before the walls again reach thermal equilibrium. Under these circumstances the thermal capacity, or the quantity of heat the walls can store, is of importance; a furnace for intermittent work, therefore, may show a higher over-all thermal efficiency if it has thin walls of low thermal capacity, even though the rate of heat loss through the walls is greater than with thicker walls. The way the furnace is to be used may influence its design.

In general, to build a given type of furnace in a larger size and to increase its power input at the same time, results in marked in-

crease in thermal efficiency, as the capacity increases faster than the wall volume and wall area, and therefore increases the ratio of usefully applied heat to the amount lost through the walls.

The relative importance of thermal efficiency depends on the cost of electric power. If power is cheap, thermal efficiency can be sacrificed for stability, convenience, or for securing other advantages that might be more readily obtained in a less efficient type; as the cost of power increases it becomes of greater importance in the cost sheet, so that the choice of a type must take account of this item and of the difference in the thermal efficiency of different types of furnaces.

ELECTRICAL CHARACTERISTICS.

For use in a given plant the furnace must be able to utilize the available supply of alternating current, either from the power house of the plant or from a central station, without undue interference with other users of power or with efficient generation of the power.

Few electric furnaces can be designed to take transmission-line voltages, and none can be so designed with safety to the users; hence transformers are always used to step high-tension current down to furnace voltages.

Some furnaces, notably direct-arc furnaces, tend to disturb the regulation of the lines on which they are located. This interference is most noticeable in the case of a furnace of high power requirements on a low-capacity line, and is especially objectionable where a single-phase furnace has to operate on one phase of a three-phase line. The type of furnace must be chosen with care, if lines of low capacity must be used; on a line of large capacity it is often possible to use without trouble a 300-kw. single-phase arc furnace.

A furnace of low power factor involves losses in the transmission of power, and power is priced higher to such a furnace than to one of higher power factor. Few furnaces operate at a power factor below 75, however, and this figure is usually satisfactory to the power plant.

The power department of a plant or the central station that supplies power to a plant proposing to install an electric furnace must always be consulted to ascertain whether the electrical characteristics of the furnace to be installed will fit the power supply of that plant or locality. Usually little difficulty is experienced in large manufacturing districts, but in isolated plants or in small communities it might not be feasible to use any electric furnace whatever because of the lack of suitable power supply.

The electrical characteristics of the furnace may affect its operation or its thermal efficiency. Attempts to get too high a power factor on an arc furnace may result in an unsteady arc. Other things being equal, the higher the voltage and the lower the current

used on a furnace the better its thermal efficiency, because the heat losses from the electrodes increase rapidly as the current increases. The electrode losses from a 100-kw. furnace taking 100 volts, 1,000 amperes, may be 5 kw., while from another 100-kw. furnace taking 25 volts, 4,000 amperes, they may be 15 kw. or higher. Arc furnaces thus usually have an advantage in thermal efficiency over resistance furnaces, which are normally designed to use a much lower voltage than arc furnaces. On the other hand, arc furnaces continually use up electrodes, while the electrodes of resistance furnaces may last for many months.

COST OF OPERATION.

As has been stated, the initial cost of any electric furnace is relatively high, so that charges for interest and depreciation can not be neglected, especially if the rate of production of the furnace is low. Cost of maintenance for refractories and electrodes is also usually higher than on fuel-fired furnaces. The final test of an electric furnace is its ability to produce, under the conditions in any given plant, molten metal of the desired quality in the ladle at a lower over-all cost than any fuel-fired furnace or any other electric furnace. The operation of a given furnace affects the cost as much as the design; therefore it is necessary to consider furnace operation separately from the design. This phase of the subject will be considered later, as regards the commercial furnaces, after a discussion of the design and of the capabilities of all hearth-type furnaces, whether now in commercial operation or not.

HEARTH-TYPE FURNACES—THEIR VARIOUS FORMS.

EXPERIMENTAL ROCKWELL FURNACE.

The W. S. Rockwell Co., furnace engineers, constructed a long time ago a tapping furnace in which metal was to be contained on a shallow refractory hearth, probably supported by refractory piers, below which was a resistor. Work on this type did not progress very far: if the floor of the hearth were made thick enough to hold up the weight of metal, it baffled too much the flow of heat, and the efficiency became very low, only about 6½ per cent, calculated from the test.

All other attempts to design a hearth-type furnace have specified that the heating of the metal should be done from the top or from the sides.

BRISTOL FURNACE.

Bristol² suggests a tilting furnace for brass with a carbon-rod resistor, a stream of steam being injected to prevent the entrance of air

² Bristol, W. H., U. S. Patent 1,315,206, Sept. 9, 1919.

and to cut down oxidation of the resistor and of the charge. An outlet is provided for the steam, and there is nothing to prevent the volatilization of zinc through such an outlet. In fact, the stream of steam would tend to sweep out the zinc vapor as fast as it should be evolved.

Instead of reducing the oxidation of the resistor, the steam would attack the resistor, just as red-hot coke is attacked by steam in the production of water gas. Steam passed over red-hot iron filings will produce iron oxide and hydrogen, and it seems very likely that an analogous decomposition of the steam would be brought about by the zinc in brass, forming zinc oxide⁶ and hydrogen, as zinc in the presence of impurities is capable of thus decomposing even liquid water.

Divine⁷ states that steam blown through a molten zinc alloy oxidizes the zinc.

SNYDER RESISTOR TILTING FURNACE.

The Industrial Electric Furnace Co. show a photograph⁸ and a diagram of a furnace in the form of a horizontal cylinder with conical ends, the melting chamber inside being spherical. The diagram shows a carbon-rod or tube resistor on the horizontal axis of the furnace. No commercial installations have been made for melting brass and according to Booth⁹ no tests were made on brass, though it was suggested that it might be available for melting nonferrous alloys.

CLINGMAN RESISTOR FURNACE.

The Clingman resistor furnace, it was stated in 1918, was being manufactured for trial in a brass and copper mill by the Columbia Electric Furnace Co. It has a carbon-rod resistor, which is said to last 70 to 120 heats, located centrally in the furnace. The furnace walls are extended nearly to the resistor, these projections being made of carbon. Above the rod the furnace has a sort of hopper shape, and below it a hearth from which metal can be poured. The furnace is designed to take 10 to 20 volts and is planned for being carried bodily to the molds for pouring. Different sizes are designed for capacities of 100 to 500 pounds per heat. The 500-pound furnace is to take 60 kw. The cold charge is to be placed over the resistor, supported by the resistor and by the carbon projections in

⁶ Compare Schenck, R., and Dean, R. S., *The physical chemistry of the metals*, 1919, p. 155.

⁷ Divine, R. D., Separation of lead, zinc, and antimony oxides: *Bull. Am. Inst. Min. Eng.*, No. 92, Aug. 1914, p. 1877.

⁸ *Electric Furnace Bulletin* No. 40, October, 1917, p. 27.

⁹ Booth, C. H., Booth electric rotating brass furnace: *Metal Ind.*, vol. 17, 1919, p. 317, par. 1.

the walls, thus being in contact with the resistor until it melts; then it drops through the space between the resistor and the wall into the hearth, where it is heated to pouring temperature by radiation from the resistor.

It is not clear how the current can be prevented from short-circuiting through the solid charge piled on the resistor rod, nor how the rod is to support the weight of the charge without breaking. No actual tests on this design have been reported, although certain claims for its performance have been made, including a claim of a consumption of power at the rate of 140 to 160 kw. h. per ton, though 140 kw. h. per ton is less than the power theoretically required in a furnace of 100 per cent thermal efficiency. It is possible to obtain such figures experimentally if heat stored in a furnace is utilized and no account taken of it. For example, one could charge a few pounds of brass into a steel furnace after pouring a heat of steel and, without using any electric power at all, melt the brass and raise it to pouring temperature. The furnace would then melt brass at an apparent power consumption of no kw. h. per ton.

STEINBERG AND GRAMOLIN FURNACE.

Two Russian inventors¹⁰ have designed another carbon resistance rod furnace, having three rods over a hearth, for three-phase current. No application of the design seems to have been made.

JOHNSON FURNACE.

W. McA. Johnson¹¹ suggests a furnace in which a resistor built up of a latticework of carbon bars is located over the hearth. Granular resistor may also be piled over the lattice. Unusual features of the furnace are a propeller-wheel stirrer set in a recess at one side of the hearth to cause circulation of the metal and an impeller pump, which is designed to circulate the gaseous contents of the vapor space to cause a gas flow from the resistor downward till it strikes the metal in the hearth; this mechanism would convey heat by the bodily motion of the hot gas as well as by radiation. It is not clear how the stirrer and the pump, which are to be made of graphite or fire clay, could be kept in steady operation without difficulty.

The furnace is designed mainly as a mixing and superheating furnace rather than as a melting furnace, and the charging opening is small. Molten copper and molten zinc in the proper proportions are to be melted in other suitable furnaces and poured into this furnace

¹⁰ Steinberg, S., and Gramollin, I., British Patent 111,679 of Dec. 13, 1917.

¹¹ Johnson, W. McA., U. S. Patent 1,243,416, Oct. 16, 1917; application filed Mar. 2, 1914.

for mixing.¹² Borings or other fine material can also be charged. This furnace has not been actually constructed or operated on brass.

FITZGERALD-THOMSON FURNACE.

The power input that can be taken by a single carbon rod used as resistor is limited, and such a rod is fragile. If its diameter should be increased to strengthen it, its resistance would be so reduced that huge currents at low voltage would be needed. If a complex resistor were built in the form of latticework, for example, there would be difficulty in building it up so that it would give uniform heating.

All such resistors to be used in a brass furnace run at temperatures so high that the refractories which support the ends of the resistors receive severe treatment. Fitzgerald¹³ built a furnace, after a design by Thomson, in which the resistor consisted of a layer of small carbon rods laid side by side, the current passing at right angles to the axes of the rods. The contact resistance between the rods was thus utilized as well as the resistance of the rods themselves. The ends of the rods were supported on magnesite ledges at the sides of the furnace, the electrodes entering from the ends, the resistor being placed over the hearth. The furnace was designed for use in carrying out the Imbert zinc-smelting process, but was also tried for melting iron and copper.

The resistor burns away when the air strikes it; a modification of the furnace provides therefore for placing a septum between the resistor and the hearth to prevent an access of air to the resistor. The septum is made of carborundum or siliconized graphite to resist oxidation and to have heat conductivity high enough to baffle the flow of heat as little as possible.

The weak point of the furnace was the support of the ends of the resistor rods, which were so hot that the supporting ledges of magnesite failed. To avoid this weakness, a resistor was designed of molded carbon plates 5 inches high, $8\frac{1}{2}$ inches long on top, $5\frac{1}{2}$ inches long on the bottom, and about an inch thick in the thickest part. These plates, instead of being flat and of uniform thickness, were ribbed or fluted; by placing alternate ones higher than the others, so that a projection fitted into a depression, the row of plates was self-supporting if the ends of the row and not the sides were held up. As the ends are held up by the large carbon or graphite electrodes, the sides of the resistor need no support and the resistor does not come in contact with any refractories.

¹² Compare also Addicks, L., U. S. Patent 1,041,940, Oct. 22, 1912; Clamer, G. H., U. S. Patent 1,198,618, Sept. 19, 1916.

¹³ Fitzgerald, F. A. J., A new electric resistance furnace: *Trans. Am. Electrochem. Soc.*, vol. 19, 1911, p. 273.

The thickness of the plates is slightly less at the bottom than at the top, so that when the resistor is assembled the long row of plates forms an arch.

This makes the lower part of the arch offer a shorter path to the current, and, added to the fact that the plates are narrower at the bottom of the resistor than at the top, means that the current density is higher on the bottom of the resistor than at the top and the resistor will heat up more at the bottom. The corrugated plates offer much contact resistance, so that of the total resistance of a row of 71 plates 98 per cent was due to the contact resistance and only 2 per cent to that of the body of the plates.

THOMSON FURNACE.

The principle of a self-supporting carbon resistor described above has been patented by Thomson in a large variety of forms.¹⁴ In the later forms the use of molded carbon plates has been given way to the use of a continuous graphite resistor which could be made from a long, square, graphite bar by shaving down the bar into a wedge shape to make the lower part of the resistor narrower than the top, as was the case in the ribbed-plate resistor, then by sawing the resistor nearly but not quite through lengthwise, giving it the shape of a U, and then making a series of smaller U's alternately upright and inverted by cutting each leg of the big U nearly but not quite through by alternate cuts from top and bottom. This gives a resistor in which the current enters one leg of the big U, takes a sinuous path around the cuts in that leg into the other leg, and again around the cuts out the second leg. The slots in this zig-zag grid are filled with some refractory material of low electrical conductivity when hot, such as alumina, and the surface of the resistor is likewise coated with it. This increases the strength and stability of the resistor and also reduces its tendency to oxidation. The cylindrical, molded graphite-fire-clay resistor used in the Snyder crucible lift-out furnace previously described was slotted in an analogous fashion to increase the resistance, and the slots were filled with aluminum cement to increase the stability. The pure-graphite resistor used in the Thomson furnace is of course capable of being run at a much higher temperature than the graphite-fire-clay resistor used by Snyder.

¹⁴ Thomson, J. U. S. Patents 950,877, 950,880, 950,882, 951,080, Mar. 1, 1910; 994,217, June 6, 1911; 1,080,862, 1,080,863, 1,080,864, 1,080,865, 1,080,866, Dec. 9, 1913; 1,298,421, Mar. 25, 1919; 1,308,877, July 8, 1919; 1,318,028, 1,318,029, 1,318,030, 1,318,031, Oct. 7, 1919; 1,321,682 and 1,321,683, Nov. 11, 1919.

The John Thomson Press Co. advertised^{14a} an electric brass furnace in January, 1919, and in February replied to an inquiry from a brass foundry that the resistor (of the style just described) is free from air burning, and therefore practically permanent. The furnace temperatures are controlled by a transformer having taps to supply 20 to 50 volts in 2½-volt steps and 50 to 100 volts in 5-volt steps at the furnace terminals. The kv.-a. capacity of the transformer is not given. Blue prints dated July 10, 1918, of a furnace to hold 1,000 pounds of brass were sent to the foundry, but it was stated that various modifications were being made in that design as a result of trial. In a test by the makers the furnace is said to have melted brass at the rate of 250 kw. h. per ton. The figure doubtless refers only to 24-hour operation.

The 1,000-pound furnace, complete with transformer, was priced at \$11,800 in February, 1919. The upkeep cost was said to be "very small."

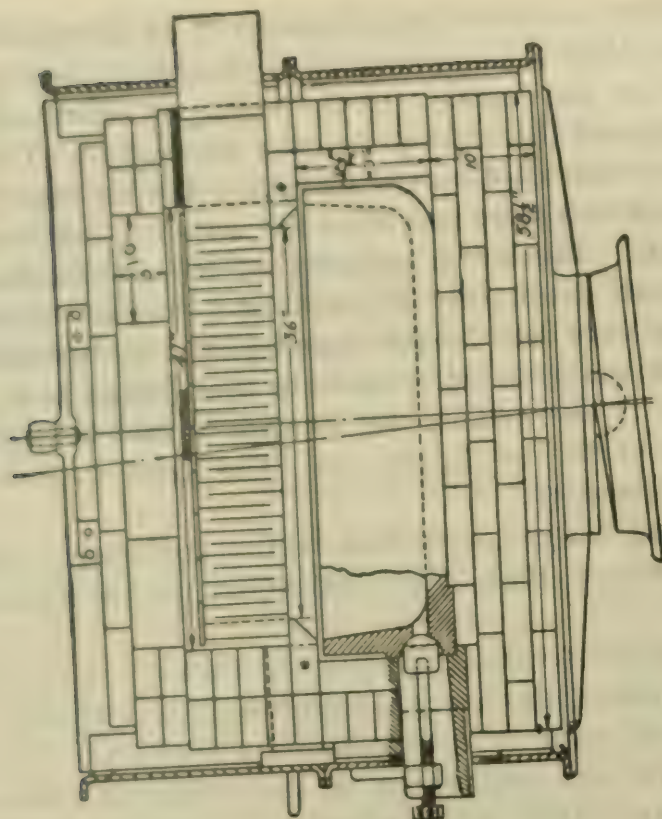
The blue prints, from which figure 11 is drawn,¹⁵ show a tapping furnace with a rectangular hearth, over which is a zigzag resistor, each end of which rests on a carborundum support. There is no septum between resistor and hearth, as the resistor is claimed to be free from oxidation. Both terminals of the single-phase circuit are connected to the ends of the resistor at one end of the furnace, the tap hole and spout being at the other end of the furnace. Charging doors are provided at the ends of the furnace. The roof is arched over the resistor in order to reflect heat upon the bath.

The whole furnace is mounted in a framework of channel iron on a base. In the center of the base is a hemispherical projection fitting into a cup in a smaller base fastened to the floor. Outside the cup the small base has a flatly conical surface. At the center of the top of the framework is a bearing with an eccentric arm. The eccentric rides a rigid bearing and is rotated by a motor through a geared and belted transmission. The motion of the eccentric arm produces a gyrating movement of the furnace, evidently designed to stir the metal and to minimize surface overheating of the bath, on the principle of stirring a bath of brass by motion of the furnace previously shown by the Bureau of Mines to be desirable in the rocking arc-furnace. A furnace motion, designed to stir the metal, of about the degree obtained in the Thomson design, was used on some of the early forms of the Stassano¹⁶ steel furnace. Flexible leads must, of course, be provided to allow the gyrating motion.

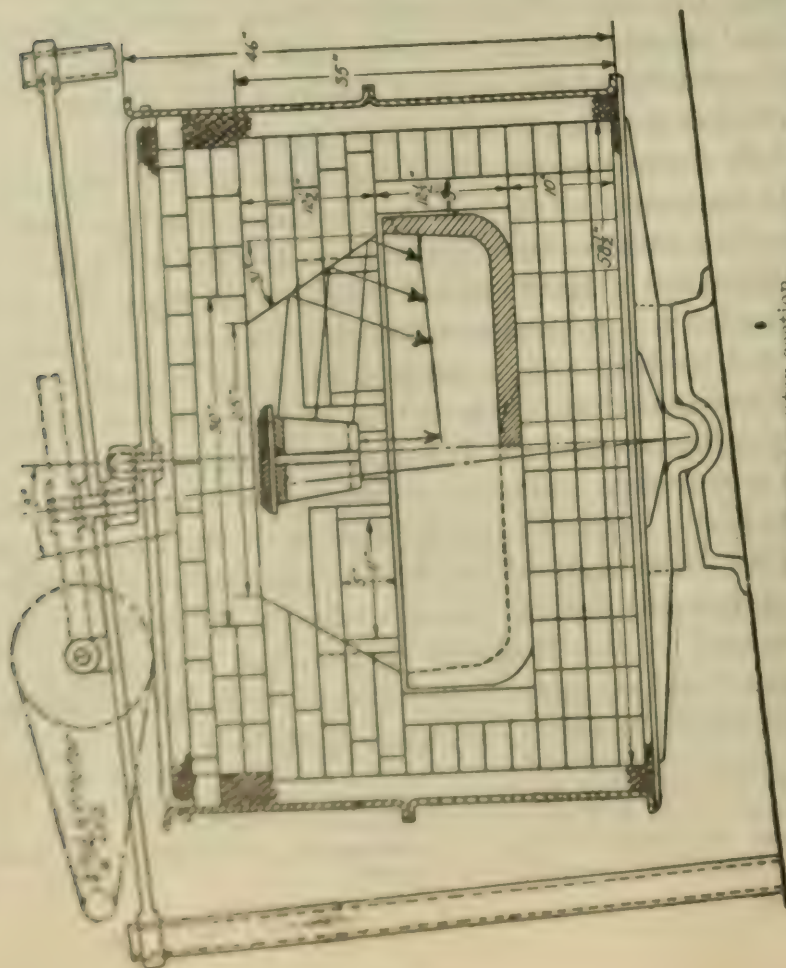
^{14a} Chem. and Met. Eng., vol. 20, 1919, advertising pages, January issue.

¹⁵ See also Thomson, J., U. S. Patent 1,308,877, July 8, 1919.

¹⁶ Rodenhauser, W., and Schoenawa, J., translated by vom Bauer, C. H., *Electric furnaces in the iron and steel industry*. 1917, p. 108.



Longitudinal center section.



Transverse center section.

FIGURE 11.—Diagram of Thomson zigzag-resistor gyrating furnace.

LATER FORM OF THE THOMSON FURNACE.

The Thomson gyrating brass furnace appears to have been abandoned in favor of a cylindrical, rotating furnace with a central, tubular zigzag resistor. The latest design is stated by Thomson¹⁷ to be based on his Patents Nos. 950,878, 950,880, 1,318,030, and 1,318,031.

The original method of protecting the resistor from oxidation by a coating of carborundum is said to have been a "disappointment," as it did not prove satisfactory under severe test. Another method is said to have been devised.

The Thomson furnace could be provided with two or three resistors in order to use polyphase power. The resistor could not be withdrawn while charging, as can the electrodes of the rocking and rotating indirect-arc types, which will be described farther on in this report. It would be necessary to exercise great care in charging in order to avoid breaking the resistor. Mechanical charging from overhead would therefore be impracticable.

If this type of furnace is made to rotate completely, the problem of maintaining a good electrical contact at the sliding contact would be even more serious than in the completely rotating arc type, as the resistor takes a lower voltage and a higher amperage than the arc.

Until foundry tests have been made to show the behavior of the Thomson furnace its value can not be predicted, for that will depend on the life of the resistor in actual practice, on the actual number of kilowatt hours needed per ton of metal, and on the rate of production, life of the lining, and on its general convenience.

HARVEY FURNACE.

Harvey,^{17a} an English designer, has described a design in which the furnace is cylindrical, with a rounded bottom and an open top, which is closed by a door carrying a solid resistor or electrodes, between which an indirect arc is struck. The furnace is pivoted at the bottom and is inclined on its side, resting on a support, as shown in figure 12. The furnace is then rocked or rotated to wash as much as possible of the walls with the metal.

The use of a solid resistor supported in this way seems hardly practicable, and the electrodes for an indirect-arc form would be in an inconvenient and cramped position.

HOSKINS OVERHEAD-RESISTOR TILTING FURNACE.

A Hoskins furnace with resistor over the bath was tested on brass, two tests being made in 1913 and 1914 at the plant of the Hoskins Manufacturing Co., Detroit, at both of which a representative of the

¹⁷ Thomson, J., Personal communication, Apr. 30, 1920.

^{17a} Harvey, L. C., U. S. Patent 1,337,839, Apr. 20, 1920.

Bureau of Mines was in attendance. Further tests were made in 1915 by the bureau in the Cornell laboratories at the bureau's field office in Ithaca.

1913 TEST.

The furnace had been designed for melting nickel-chromium alloys and consisted of a rectangular iron box built up from sheet iron and

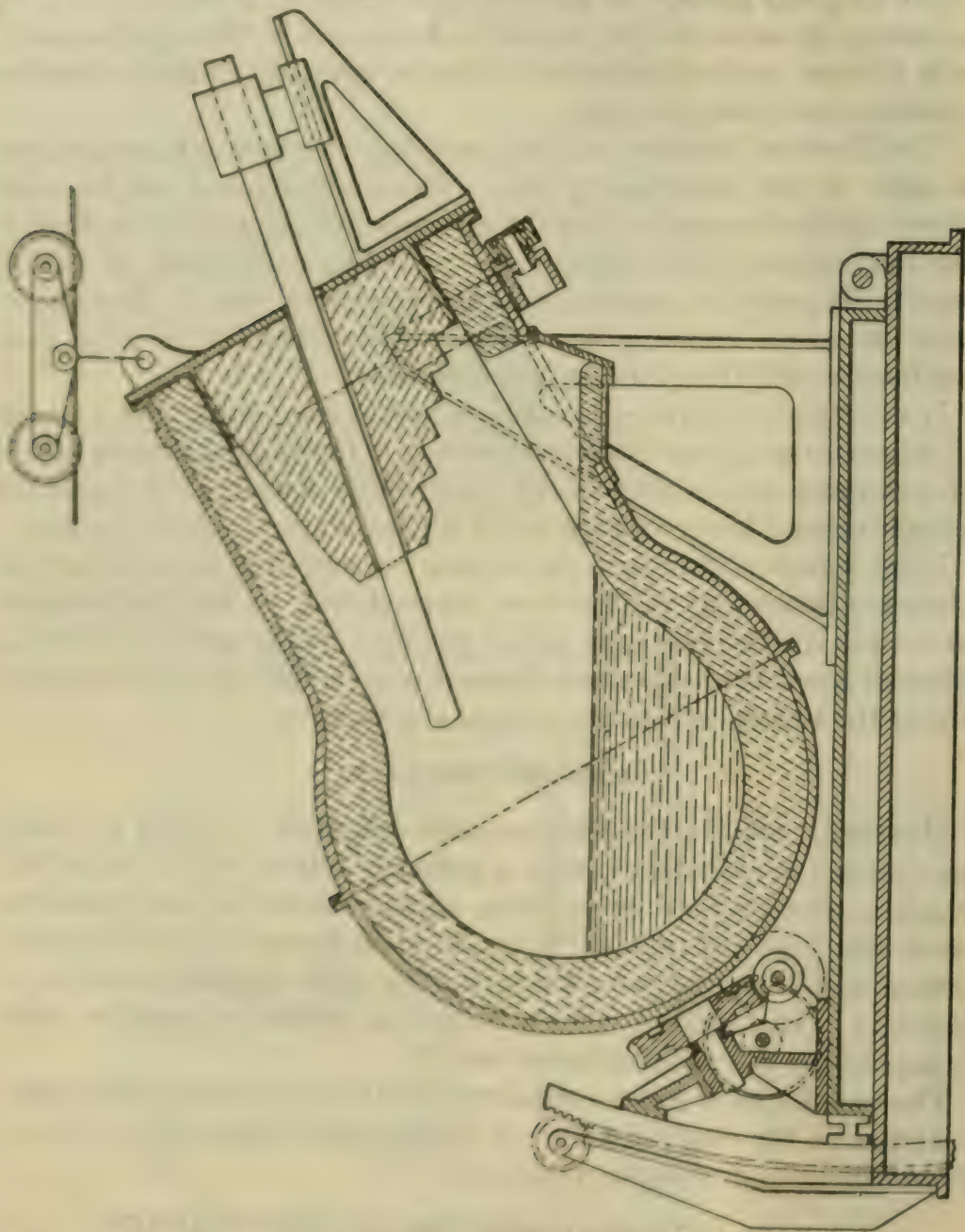


FIGURE 12.—Harvey rotating furnace.

angle iron 37 by 38 by 23 inches high and had a cover 30 by 31 by 7 inches thick. Figure 13 is a diagrammatic sketch showing the principle. The shell was lined with infusorial earth for about $1\frac{1}{2}$ inches, then with $1\frac{1}{4}$ inches of crushed magnesite, and then with 4 inches of magnesite brick. A melting hearth 13 inches square and about 6

inches deep was covered smoothly with magnesite. This hearth was provided with a pouring spout also lined with magnesite, which led into a lip provided on the furnace shell. This spout had also to serve as the charging door, although the opening was only about 5 inches in diameter.

Over the melting hearth the sides were so built up of magnesite bricks as to give an opening about 15 inches square. Two opposite sides had the bricks so placed as to form ledges for the support of the resistor. This resistor consisted of some 60 flat carbon plates

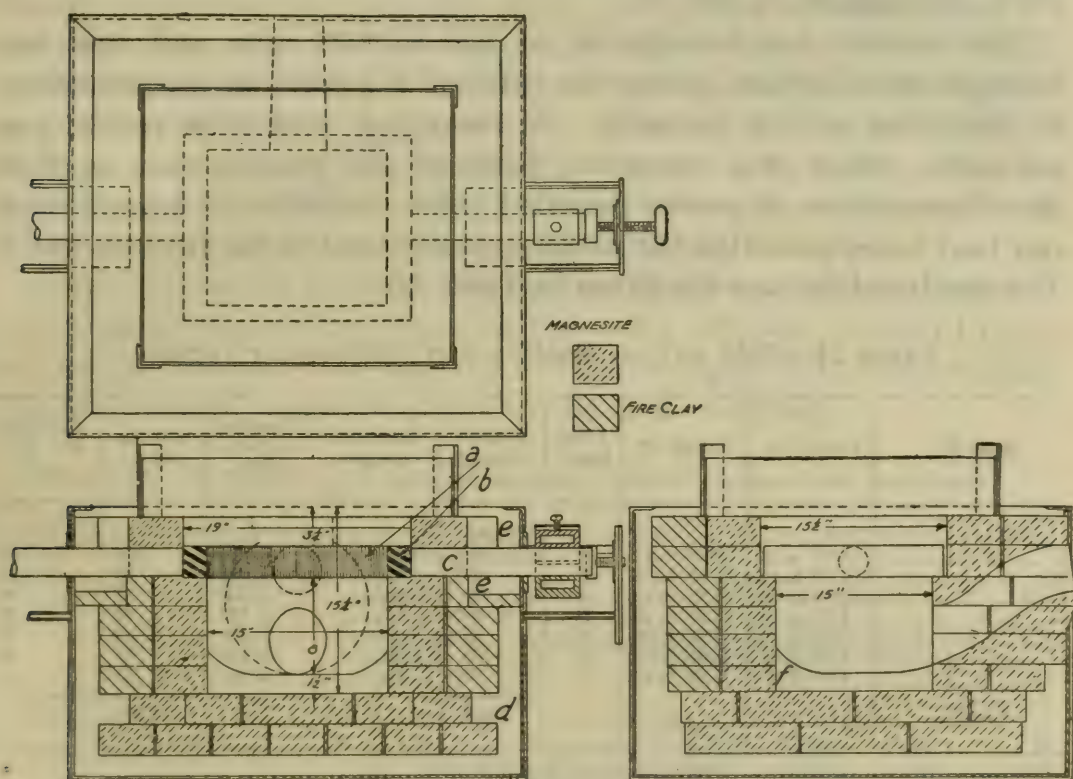


FIGURE 13.—Diagram of Hoskins overhead-resistor tilting furnace: *a*, Carbon resistor plate; *b*, graphite front plate; *c*, graphite electrode; *d*, fire-sand pocket; *e*, infusorial earth; *f*, magnesite.

$2\frac{1}{2}$ by $\frac{1}{4}$ by 15 inches, placed side by side, thus giving a carbon resistor 15 by 15 by $2\frac{1}{2}$ inches high over the hearth.

At the sides graphite “push blocks” were provided, by means of which, as they were crowded in or loosened by the screw-regulating device, the contact resistance of the plates in the resistor could be altered at will.

The lower surface of the carbon resistor was 6 inches from the bottom of the melting hearth. The roof or cover, which could be lifted off bodily by a crane, was 1 inch above the upper surface of the carbon resistor and consisted, next to the resistor, of a layer of carbon slabs $1\frac{1}{2}$ inches thick. Above the carbon slabs was $3\frac{1}{2}$ inches of fine magnesite, and above this infusorial earth $1\frac{1}{2}$ inches thick at the edges of the cover and crowned up to $2\frac{1}{2}$ inches or 3 inches at the center.

Two different alloys were melted in the furnace, the first having approximately the following composition: Cu, 88.4 per cent; Sn, 7.3 per cent; Pb, 2.0 per cent; Zn, 2.3 per cent. This is one grade of leaded gun metal; it should melt at about 985° C. and will be called "alloy A." The other alloy, which will be called "alloy B," had approximately the following composition: Cu, 76 per cent; Sn, 1 per cent; Pb, 1 per cent; Zn, 22 per cent. This alloy is about midway between ordinary red and yellow brass and would be commercially termed a "half-yellow half-red" metal, which should melt in the neighborhood of 920° C.

The current was brought in at 220 to 240 volts and was run through transformers giving the ratio of 27½ volts on the secondary to 220 volts on the primary. A recording watt-hour meter was provided, which was connected back of the transformer, so that the consumption of power recorded below includes all transformer and lead losses as well as the power actually used in the furnace itself. The results of the test are given in Table 24.

TABLE 24.—1913 test on Hoskins overhead-resistor furnace.

Hest No.	Power on.	Power off.	Alloy used.	Weight of charge.	Material charged.	Pouring temperatures.	Kw. h. used.	Average kw. input. ^b
				Pounds.		° C.		
1	8.15 a. m.	11.00 a. m.	A	103½	Gates.....	1,210	115	42
2	11.16 a. m.	11.55 a. m.	B	95½	...do.....	1,065	33	47
3	12.30 p. m.	1.40 p. m.	A	96	Ingot.....	1,220	47	40
4	1.53 p. m.	2.23 p. m.	B	93½	...do.....	1,120	23	46
5	2.33 p. m.	3.14 p. m.	A	95	...do.....	1,210	32	49
6	3.27 p. m.	3.54 p. m.	B	93	...do.....	1,125	21	48
7	4.05 p. m.	4.36 p. m.	A	94½	...do.....	1,220	24	48
Total				668			c 295	

^a Furnace first heated empty. Charging begun at 8.46 a. m.

^b The furnace was cold at start and when first started up took 28½ volts, 1,400 amperes, about 40 kw.

^c Average mill kw. h. per ton.

Of the charge 658½ pounds of metal were recovered, the loss being 1.4 per cent. It appeared from this test that a higher power input would be desirable, that the hearth should be of greater capacity, and the charging door should be enlarged. These changes were made and another test was run at the plant of the Hoskins Manufacturing Co. in 1914, at which one of the writers was again present.

1914 TEST.

The furnace was rebuilt by deepening the hearth, so that instead of its bottom being but 6 inches from the bottom of the resistor blocks, it was 10½ inches from them in the center and 8 inches at the sides. The molten charge was about 4 inches deep at the center. The pouring spout and charging hole was increased in size to an oval hole 7½ by 5 inches, and the opening into the furnace was tapered

back so that all parts of the hearth could be seen and could be reached easily with a poker. By slightly tilting the furnace back it could be readily charged. Instead of a maximum of 55 to 60 kw., which was all the power available in the first test, up to 85 or 90 kw. could be drawn.

The blades were supported on two carborundum (Refrax) slabs 2 inches thick by 4 inches wide by 16 inches long, so laid that about 1 inch of the slab extended out beyond the inner wall of the furnace. On top of the slabs was put $\frac{1}{4}$ inch of magnesite cement to reduce leakage of current through the slabs. The damp cement was covered with thin strips of cardboard to prevent the blades from sinking into the magnesite before it was dry. It was found to be more convenient to build the furnace so as to allow a 2-inch space between the top of the resistor blades and the bottom of the carbon slabs in the cover instead of the 1-inch space used in the previous test. Tests on red and yellow brass are shown in Tables 25 and 26.

Before the test of Table 25 the furnace was heated up slowly for a short time till the melting chamber showed a dull red, in order to dry out the new hearth. The furnace was not brought up to full running temperature and was only at 95° C. the next morning.

TABLE 25.—1914 test of Hoskins overhead-resistor furnace on red brass.

[An alloy of 83 per cent Cu, 7 per cent Zn, 4 per cent Sn, and 6 per cent Pb was melted, ingot metal being charged.]

Heat No.	Power on.	Power off.	Weight of charge.	Pouring temperature.	Kw. h. used.	Average kw. h. input.
			Pounds.	° C.		
1.....	7.13 a. m.	9.33 a. m.	231½	1,200	163	70
2.....	9.50 a. m.	10.51 a. m.	282	1,180	81	82
3.....	{11.15 a. m.	12.00 m.	300	1,200	63	63
	{12.47 p. m.	1.00 p. m.				
4.....	1.15 p. m.	2.16 p. m.	300	1,160	65	65
5.....	2.28 p. m.	3.24 p. m.	300	1,200	49	53
6.....	3.45 p. m.	4.50 p. m.	300	1,150	52	45
Total.....			1,713½	.....	a 473	.....

a Average 555 kw. h. per ton.

Metal losses were not taken, since a crack developed at the upper part of the hearth, through which considerable metal was lost into the furnace lining.

The test on yellow brass, given in Table 26, was made the next day after the test of Table 25 and started with the furnace chamber at 540° C., no power having been used at night. Ingot metal of 66 per cent copper, 33 per cent zinc, and 1 per cent lead was melted.

TABLE 26. — 1914 test of Hoskins overhead-resistor furnace on yellow brass.

Heat No.	Power on.	Power off.	Weight of charge.	Pouring temperature.	Kw. h. used.	Average kw. input.
			Pounds.	°C.		
1	7.08 a. m.	8.40 a. m.	253.50	1,050	100	66
2	8.52 a. m.	9.52 a. m.	250.00	1,070	64	64
3	10.03 a. m.	10.50 a. m.	250.25	1,050	44	57
4	11.03 a. m.	11.51 a. m.	252.75	1,070	49	61
5 ^a	12.30 p. m.	1.08 p. m.	250.75	1,050	35	55
6	1.19 p. m.	2.09 p. m.	250.00	1,050	50	60
7	2.20 p. m.	3.06 p. m.	250.00	1,060	44	73
8	3.15 p. m.	4.02 p. m.	253.00	1,050	35	48
Total			2,014.25		d 421	

^a Part of metal charged at 12.10 p. m.^b Power input increased on this heat.^c Power input lowered on this heat.^d Average, 420 kw. h. per ton.

The metal poured weighed just a ton, the loss being 0.7 per cent and varying on individual heats from 0.6 to 0.8 per cent. The charges were reduced to 250 pounds on this run in order to keep the metal level below the crack in the hearth and to make it possible to obtain figures on the loss in metal.

On both these tests the time occupied in pouring was excessive, as suitable ladles were not at hand. Without this delay 2,000 pounds of red brass or 2,500 pounds of yellow brass could have been melted in a 9-hour day. This would have made it possible to melt red brass on 9-hour operation with about 500 kw. h. per ton and yellow brass with about 400 kw. h. per ton. Had the hearth been tight, so that 300-pound charges of yellow brass could have been made, the production should have been about 2,700 pounds at something under 400 kw. h. per ton. On 24-hour operation the 300-pound furnace should operate at about 325 kw. h. per ton of red brass heated to 1,200° C. or 275 kw. h. per ton of yellow brass.

The resistor (which was made up of the same plates as were used in the 1913 test), the carborundum slabs, and all parts of the furnace were in good shape save for the crack in the hearth.

The increase in furnace capacity and in power input had made the furnace much more efficient than it was in the 1913 test. Through the courtesy of the Hoskins Manufacturing Co. the furnace shell was loaned to the Bureau of Mines for further experimenting.

While the carborundum ledges on which the resistor plates rested were in good condition after these runs, the ledges gave trouble from spalling when the furnace was used later by the Hoskins Manufacturing Co. for melting nickel-chromium alloys. The furnace was not used enough on nickel-chromium alloys to show how serious this difficulty was; carbon flaked off from the resistor and dropped into the bath, doing no damage on brass, but great damage on nickel-chromium alloys.

BUREAU OF MINES TESTS OF HOSKINS OVERHEAD-RESISTOR FURNACE.

Two carbon rafters were placed over the hearth, pure-white alundum slabs, the most refractory grade, $\frac{1}{2}$ inch thick, were put over them for electrical insulation, and carborundum slabs 1 inch thick were placed on top of the alundum. If the resistor plates, which ran at above 1,800° C., were put directly on the alundum, the alundum was attacked and some aluminum carbide and nitride was formed.

In order to increase the voltage required, 12-inch resistor plates were used instead of the former 15-inch plates. A run was made on red brass of 81½ per cent copper, 8½ per cent zinc, 4 per cent tin, 6 per cent lead, made up of about 40 per cent scrap copper, lead, and tin, 40 per cent yellow chips, and 20 per cent gates. The furnace was cold at the start. The metal was poured at 1,120° C. The results of the test are given in Table 27.

TABLE 27.—Test of Hoskins overhead-resistor furnace made by the Bureau of Mines.

Heat No.	Power on.	Power off.	Weight of charge.	Kw. h. used.	Average kw. h. input. ^a
			Pounds.		
1.....	8.00 a. m..	10.52 a. m..	300	172	60
2.....	11.00 a. m..	12.19 p. m..	300	68	52
3 ^b	1.00 p. m..	2.11 p. m..	300	61	58
4.....	2.18 p. m..	3.38 p. m..	300	66	51
5.....	3.43 p. m..	4.58 p. m..	300	59	47
Total.....			1,500	c 426	

FURNACE AT 575° C. NEXT MORNING; NO POWER ON OVERNIGHT.

1.....	8.00 a. m..	9.57 a. m..	300	113	57
2.....	10.15 a. m..	11.35 a. m..	300	87	66
3.....	11.48 a. m..	12.26 p. m..	206	38	60
Total.....			806	d 238	

^a With the furnace hot from the previous day's run, the first two heats used but 200 kw. h. and took 3 hours and 35 minutes against 240 kw. h. and 4 hours and 19 minutes when starting with a cold furnace. Therefore, on regular 10-hour operation the power consumption would drop 40 kw. h. on the first two heats, and 40 kw. h. could be used on a 200-pound heat at the end, so that the output would be 1,700 pounds with 425 kw. h., or 500 kw. h. per ton.
^b Charge in, no power on at 12.24 p. m.
^c Average, 520 kw. h. per ton.
^d Average, 580 kw. h. per ton.

These energy figures check those calculated from the previous run on red brass. A higher power input was used on the previous run, which would give a higher efficiency, other things being equal, but the metal was not heated as hot as in the previous run. Other tests gave similar results to the one above cited. Notwithstanding that the borings were oily and the gates and scrap somewhat dirty, the gross metal loss on these runs was 1.9 per cent.

The figures of consumption of power and of the metal loss are low enough on this type of furnace to make it a possible competitor of fuel-fired furnaces, as crucibles are eliminated. But the furnace has

several drawbacks. The resistor will require replacement from time to time and to replace it without allowing the furnace to cool would be difficult. In the small 300-pound size only a small charging door can be provided, so that much labor is required to charge the furnace. As the capacity is increased the mechanical difficulties in supporting the resistor increase, so that a self-supporting resistor of the Thomson type—if that proves practical—would be preferable for large furnaces, even at the sacrifice of the many advantages of a resistor whose resistance can be adjusted.

The overhead-resistor furnace with a resistor nearly as large as the surface of the hearth, worked satisfactorily on 300-pound charges of yellow brass, showed no signs of surface overheating, and required no agitation of the metal to prevent zinc losses. The question of uniformity of product was not studied. The agitation in the Thomson furnace may be needed because of the small radiating area of the resistor, which gives a more localized source of heat. It is a question how much effective stirring a slight gyrating motion will give. If it mixes the metal, it might be a desirable feature on a large furnace with a rather deep bath in which gravity may cause the alloy to be richer in heavier constituents at the bottom of the crucible.

HOSKINS TILTING FURNACE WITH RESISTORS AT THE SIDES.

After the Hoskins Manufacturing Co. found that the overhead resistor would slowly disintegrate and allow carbon powder to drop into the bath, thus ruining their nickel-chromium alloys, another tilting furnace was built in which the hearth was placed between and below two rows of resistor blades set upright on two sides of the furnace, a carborundum slab about 1 inch thick and 4 inches high being placed outside and 1 inch away from each row of resistor plates, resting on the carborundum bricks on which the resistors also rested. The purpose was to form a pocket to catch any carbon powder that fell off the resistors and prevent it from dropping into the bath. This furnace was never tried for brass, and little work was done in it for nickel-chromium alloys, as an induction furnace was installed and attention was diverted to that type. Some difficulties were encountered in maintaining the refractories back of the resistor and in the roof.

FURNACES WITH CARBORUNDUM RESISTORS.

Silicon carbide (carborundum or crystolon) is the only refractory material, save carbon or graphite, available in commercial quantities that does not fuse or soften at 2,200° C., is not affected by a reducing atmosphere at that temperature, and is oxidized very slowly. It can be made into bricks or shapes, and its resistivity at around 2,000° C.

is of the same general order as that of a granular carbon resistor. It has been often suggested as a resistor material for electric furnaces.

Unlike carbon, when cold the resistance of silicon carbide is very high and the slope of its temperature-resistivity curve is great. It is therefore necessary either to impress a very high voltage on the resistor when starting from the cold or to preheat the carborundum to a red heat, when it will begin to carry current at a reasonable voltage.

Both the General Electric Co. and the Westinghouse Co. have experimented with carborundum resistors, and Thornton¹⁸ has described such a resistor for use in electric furnaces for heating steel, for forging, heat treatment, and annealing. He says that it might be possible to apply such a furnace to the melting of brass and copper.

When a carborundum trough is used, as in the Baily furnaces, to contain a resistor of granular carbon, it carries current and becomes, in effect, a part of the resistor. In designing an electric furnace in which carborundum is to be used as a refractory lining it is necessary that suitable insulation, such as alundum, should be used where hot carborundum would allow a flow of current at points where such flow is not desired.

EXPERIMENTAL CARBORUNDUM RESISTOR FURNACE.

The work of the Bureau of Mines on the triple lift-out Hoskins-type furnace showed the advantages of generating heat within the mass to be heated instead of outside it. As a result it seemed probable that if a furnace could be made in which the metal was contained in two hearths, with a resistor between them and in contact with the metal in both hearths, it would be thermally efficient. Obviously such a resistor made as a septum between two hearths should be metal tight, and hence should be built permanently into the masonry of the furnace; it could not be made of any short-lived material. It should have a high specific resistance, as its cross section must be large compared to its length. Fine carborundum powder, mixed with 10 per cent of alundum cement to increase the resistance of the mixture, bonded with a little dextrin, was tried as a resistor material.

The furnace was made of an old cast-iron sink lined with fire brick, to give a chamber about 9 by 22 by 9 inches. This was divided into two hearths 9 by 9 by 9 inches by a central septum 4 inches thick, which was built as follows: Two split carborundum brick (Refrax) 9 by $4\frac{1}{2}$ by $4\frac{1}{4}$ inches were set up $1\frac{1}{2}$ inches apart and cemented in place by alundum cement. The space between them was rammed full of the dampened carborundum, alundum, dextrin

¹⁸ Thornton, F., jr., A resistance furnace: Trans. Am. Electrochem. Soc., vol. 32, 1917, p. 141; see also Thornton, F., jr., and Colby, O. A., U. S. Patents 1,306,289, 1,306,250, and 1,306,251, June 10, 1919.

mixture, which was then baked. Two other split carborundum brick (Refrax) were placed on top of the others, cemented into place, and the space between them was rammed full of alundum cement, which was then baked.

The furnace then contained two hearths, each a 9-inch cube, separated by a septum 4 inches thick, the upper half of which had a nonconducting alundum layer inside it and so could not act as a resistor, but the lower half was solid carborundum on the sides and carborundum plus a little alundum tamped in the center. Graphite electrodes were set vertically into each hearth, so that with the septum hot enough to carry current and the hearths half full of molten metal the current would enter one electrode, pass through the metal in one hearth, through the resistor, out into the metal in the other hearth, and thence out the other electrode.

A Y spout connected each hearth to a central pouring spout and the furnace was arranged to tilt for pouring. The resistor was heated by placing granular carbon in each hearth and bridging over the septum with a graphite U, one leg of which reached down into the granular carbon on each side. Current was turned on and the furnace warmed up by the granular carbon. After the septum (the resistor) was hot enough to carry current the graphite U was pulled out, the granular resistor dumped out, and brass borings were charged into each hearth to make connection between electrodes and resistor. The furnace took 2,000 amperes at about 6 volts; that is, about 12 kw. The power input could not be raised, as 2,000 amperes was the limit of the power supply. Most of the furnace lining was still rather cool; hence the power input was only adequate to partly fuse the brass borings and to stick them together near the resistor.

The furnace was cooled, the brass taken out, and a test made with aluminum, as it was obvious that 2,000 amperes would not give power enough to melt brass.

The furnace was preheated with the graphite U in place and with granular carbon in the hearths, 12½ kw. h. being thus used. The U was then removed and the current was passed through the granular resistor and septum to heat the furnace more; 10½ kw. h. were thus used, or a total of 23½ kw. h. preheat. The granular resistor carbon was then dumped out and borings and ingot of 92 per cent aluminum and 8 per cent copper were put in as rapidly as the furnace would melt them. In 1½ hours 51½ pounds of the aluminum alloy had been melted, raised to 720° C., and poured; 27½ kw. h. were used in melting, or a grand total of 50½ kw. h. from the cold start.

The voltage fell to about 8, with 2,000 amperes flowing, in about 10 minutes after the cold metal had first been charged and ran very steadily at those figures. The voltage was taken across the electrodes,

but the kw. h. of figures include also all lead losses. Probably half of the voltage drop was due to the resistance of the molten aluminum.

Considering the small size and the low power input of the furnace and the absence of a roof, the hearths being left open to the air to permit of observation, the power consumption alone was not unpromising; the high current required, however, made the furnace useless, and it was torn down. The carborundum in the center of the resistor had formed into larger crystals and had begun to decompose into silicon and graphite, showing that in the center of a 4-inch resistor, both sides of which were in contact with metal at not over 720°C ., a temperature of over $2,200^{\circ}\text{C}$. had been reached.

For any such design to be of value some resistor material or mixture of materials of high resistance, of high melting point, and of high thermal conductivity is required.

Tungsten powder might make a good material for such a resistor, as it melts at about $3,000^{\circ}\text{C}$. and has a high thermal conductivity; but its electrical resistance is too low and it would have to be mixed with some refractory nonconductor. Chemically pure zirconia might serve for this purpose, as most chemically pure metallic oxides are nonconductors at high temperatures, and pure zirconia is said to melt only at about $2,600^{\circ}\text{C}$. Zirconia, however, has a low thermal conductivity. The cost of these materials makes any attempt at working out this plan for a brass furnace out of the question at present.

It was found later that Massip¹⁹ had suggested a similar type of furnace, but no data are available concerning it. Two brass furnaces using carborundum resistors have been described in the patent literature.

WEIDENTHAL FURNACE.

Weidenthal²⁰ describes a cylindrical tilting furnace for melting brass, bronze, and aluminum, the axis of the cylinder being vertical. The hearth is in the bottom of the furnace, and three groups of vertical-rod resistors for three-phase current are set upright around the inside of the furnace chamber, above the hearth. An arched roof reflects the heat downward upon the bath. The resistor rods are made of carborundum fire sand suitably bonded, with an outer coat of pure carborundum. When cold, carborundum is practically a nonconductor of electricity, but when raised to a white heat it conducts the current nearly as well as carbon; it is necessary as a result to provide some means for heating the resistors when starting from the cold. At least one resistor in each phase is made hollow and is filled with

¹⁹ Massip, G., U. S. Patent 1,005,725, Oct. 10, 1911.

²⁰ Weidenthal, H. G., U. S. Patent 1,304,425, May 20, 1919.

a granular carbon resistor that carries the starting current. As the adjacent resistors become heated by the radiation from the cored starting resistor they also begin to carry current and finally all become hot and carry current.

The resistors stand upon a ring-shaped carbon or graphite electrode embedded in the bottom of the furnace. The upper ends of the resistors stick out of the roof of the furnace and are there clamped to the conductors. On account of the liability of such a resistor to break, the system of connections has been designed to allow the ready replacement of any resistor rod that has failed.

It is not clear how particles of resistor, of refractory lining, or of other dirt are to be kept from falling down on the lower electrode when a ruined resistor rod is withdrawn for replacement, nor is it plain how such particles are to be cleared away before inserting a new resistor. The presence of such particles would prevent proper contact between the electrode and resistor. If any tests have been made on this furnace no results have been made public.

The question of the uniform molding of a molded resistor, such as carbon graphite or carborundum, which have negative temperature coefficients of resistivity, is involved in such a resistor. Unless they are uniform the old "hot-spot" trouble will be encountered.

The furnace walls, against which the resistors are placed, would have to be extremely refractory to stand up under the resistor temperature required to melt brass in such a furnace with reasonable efficiency.

Krieger²¹ suggests the use of carborundum plus a small amount of powdered metallic silicon (6 per cent), with or without a smaller amount ($\frac{1}{2}$ to 2 per cent) of powdered metals of the iron or silicon groups. The mixture is bonded with a temporary binder, such as tar or glucose, pressed into shape, and baked. The silicon is said to form an oxidation-resisting coating on the outside and to give sufficient electrical conductivity to the mass to allow ready starting from the cold. Such a resistor is said to be capable of operating unchanged in the air at a temperature of 1,500° C.

ERICHSEN FURNACE.

Erichsen²² suggests a tilting brass furnace in which the metal is held in a rather flat, shallow hearth, heating being done by one or two rows of carborundum rod resistors over the metal. Above the resistors is a preheating chamber, the floor of which forms a false roof over the resistors. This floor is sloped so that the preheated metal may be poked down (or run down if it melts) into the hearth through an opening in the center of the floor.

²¹ Krieger, M. L. U. S. Technical Electric, French Patent 497,305 of Apr. 4, 1919.

²² Erichsen, A. M. U. S. Patent 1,367,364, Feb. 1, 1921.

The resistors are placed on each side of the space below this opening, but not directly beneath it, to avoid breakage. The preheating chamber is roofed over and the furnace is charged through the roof, or the preheating chamber may be omitted when the roof over the resistors is the roof of the furnace. In that case charging may be done either through the center of the roof, the resistor rods being arranged as before, or the resistors may be placed all along the furnace and the charge introduced from the side, below the resistors.

The resistors are to extend clear through the furnace and are to be freely movable to allow expansion and contraction without breaking.

On account of the complicated construction in the hot zone and the many difficulties connected with the use of carborundum resistors the value of this furnace seems doubtful.

· DIRZUWEIT FURNACE.

Some years ago a brass furnace of the tapping-hearth type of 800 pounds capacity was erected at the plant of the Baltimore Tube Co. by J. F. Dirzuweit. This was provided with three arched troughs for three-phase current, raised above the hearth on refractory piers and containing granular carbon resistors. Great trouble was encountered with "hot spots" in the resistor, and the furnace showed an excessive power consumption. After about 2 tons of metal had been melted the furnace was abandoned.

BAILY TILTING FURNACE.

Of all the furnaces so far described in this report many have existed only on paper, a few have had laboratory tests, still fewer have been tried out under foundry conditions, and not one has yet had any steady commercial use for brass melting. The next furnace on the list, the Baily,²³ has had commercial success. The present Baily tilting furnace is the outgrowth of the unsuccessful experiments made with the different types of former Baily furnaces previously described.

This Baily furnace, like its predecessors, uses a granular resistor. Hirsch²⁴ made an exhaustive study of granular resistors and came to the conclusion that any attempt to make a granular-resistor furnace for heating steel for forging, with the steel placed above the resistor, would fail if the steel had to be heated above 1,000° C. The lower part of the resistor became so hot that failure of the silicon-

²³ Baily, T. F., and Cope, F. T., U. S. Patents 1,176,018, Mar. 21, 1916, and 1,272,186, July 9, 1918; Baily, T. F., Resistance-type furnaces for melting nonferrous metals: Chem. and Met. Eng., vol. 21, 1919, p. 11; Anonymous, Note on operation of electric furnaces: Elec. World, vol. 71, 1918, p. 780.

²⁴ Hirsch, A., Electric furnaces for heating steel: Jour. Ind. Eng. Chem., vol. 6, 1914, p. 533.

carbide (carborundum) resistor trough ensued. Thornton²⁵ made similar experiments, found a temperature of 2,000° C. in the bottom of the resistor when the steel was heated to 1,000° C., and decided that 900° C. was the upper limit to which steel could be heated in such a furnace with safety to the granular resistor. He shows how the radiation of heat from the open top of the resistor trough forces the current to concentrate in the bottom of the trough. Dow²⁶ suggests that the resistor be so arranged with respect to the iron that the magnetic force set up would tend to bring the current to the top of the resistor.

Thomson has suggested²⁷ the use of the zigzag trapezoidal resistor previously described (p. 104) in the bottom of the heating trough, with the wider side down, to avoid concentration of current in the bottom of the trough and consequent overheating of it. Granular resistor is piled over the zigzag resistor and helps to pre-

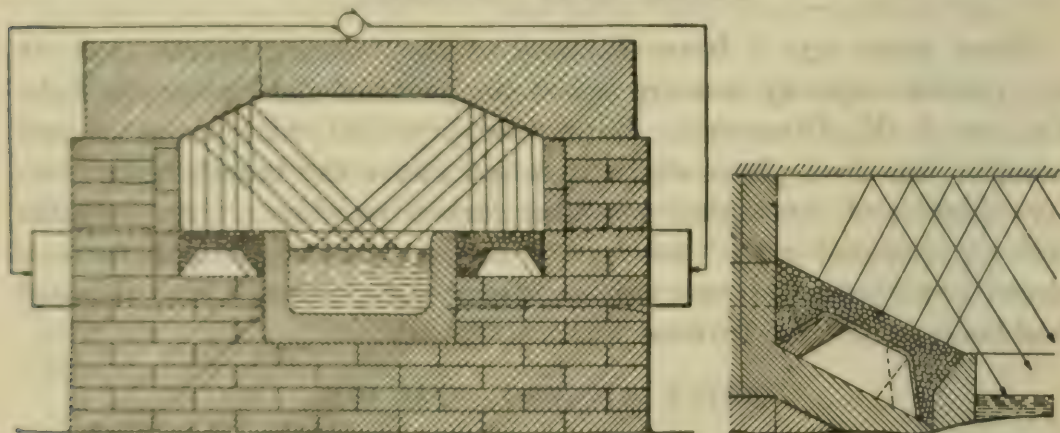


FIGURE 14.—Thomson's suggestion for improving the life of resistors in a reflected-heat furnace.

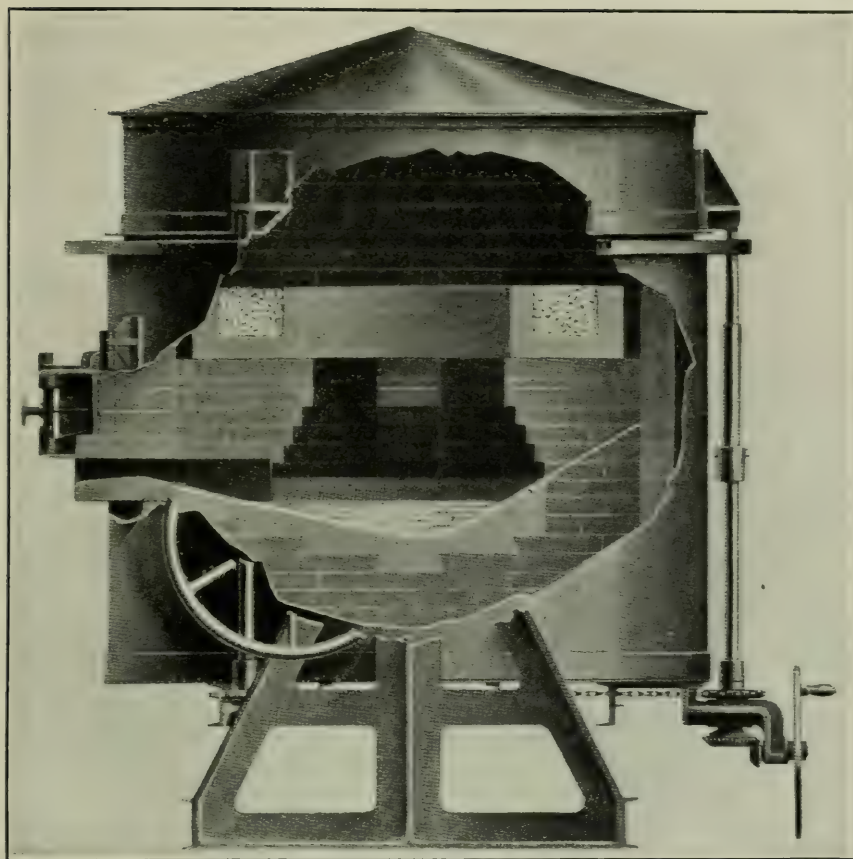
serve it from oxidation. Two adaptations of this design are illustrated in figure 14. Theoretically, this device should allow the use of a higher rate of power input without damage to the trough, and should thereby improve the efficiency of the furnace. Whether it will be a practical improvement can only be told by trial.

The standard 195-kilowatt Baily furnace, Plate VI, *A*, is an upright cylinder about 6 inches high by 7 inches in diameter, mounted on trunnions to tilt (a nose-tilting type is made also) and consists of the cylindrical furnace inclosure surmounted by a domed roof, which can be raised by a handwheel and gearing to allow charging fresh resistor material, and having the hearth in the bottom. A charging opening closed by a plug-type door is provided on the side, and in the lower part of this opening is the pouring spout. The source of

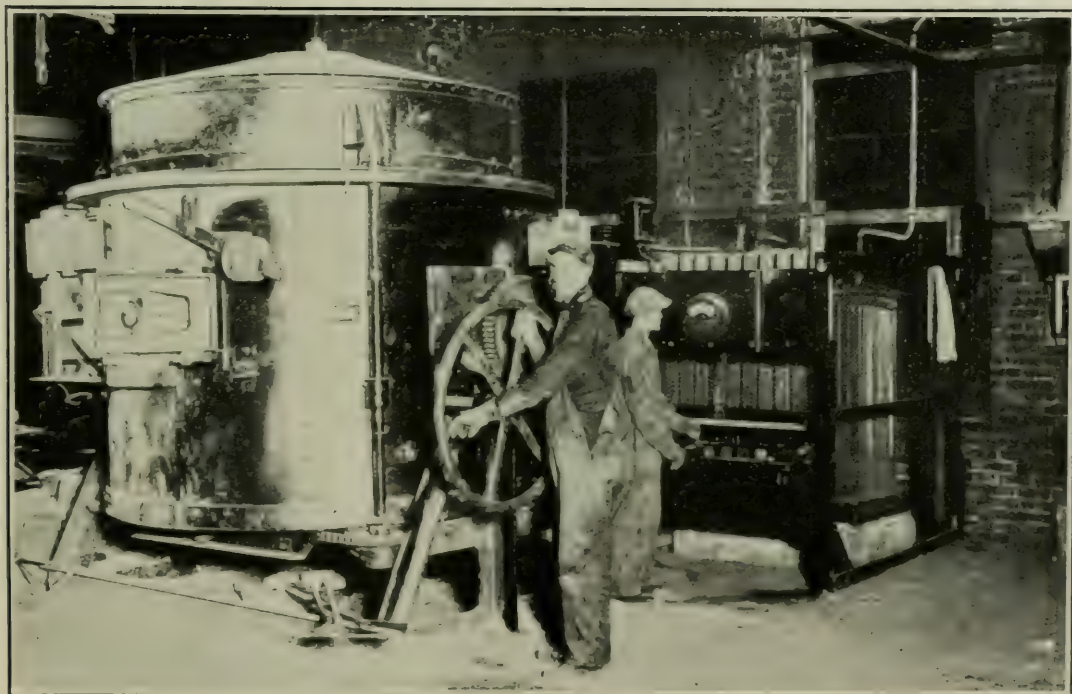
²⁵ Thornton, F. J., A resistance furnace: Trans. Am. Electrochem. Soc., vol. 32, 1917, p. 257.

²⁶ Dow, A. U. S. Patent 1,191,934, Nov. 23, 1915.

²⁷ Thomson, J. U. S. Patent 1,351,977, Sept. 7, 1920.



A. STANDARD 105-KW. BAILY FURNACE.



B. TRUNNION-TYPE 105-KW. BAILY FURNACE.



NOSE-TILTING TYPE 105-KW. BAILY FURNACE.

heat is in a circular resistor trough, placed about midway between roof and hearth. Carbon electrodes enter the resistor trough from two sides of the furnace, the single-phase current thus dividing and passing through both sides of the circle in parallel. (See fig. 15.) The electrodes are large, so that the density of the current is low, and do not heat up enough to require water cooling. They are led in through a packing of carborundum fire sand to prevent an access of air to the electrode at any point where they may become hot enough to oxidize. The electrodes are stationary, being built into the refractory wall, and require no adjustment when the furnace is running. They are usually replaced whenever the resistor trough is renewed.

The fundamental point that makes possible the use of a granular resistor in the standard Baily furnace is the recognition of this crowding of the current to the bottom of the trough and arranging the trough to allow free radiation from bottom and sides of the trough as well as the top. The trough is raised off the furnace bottom by refractory piers. A free space is provided outside

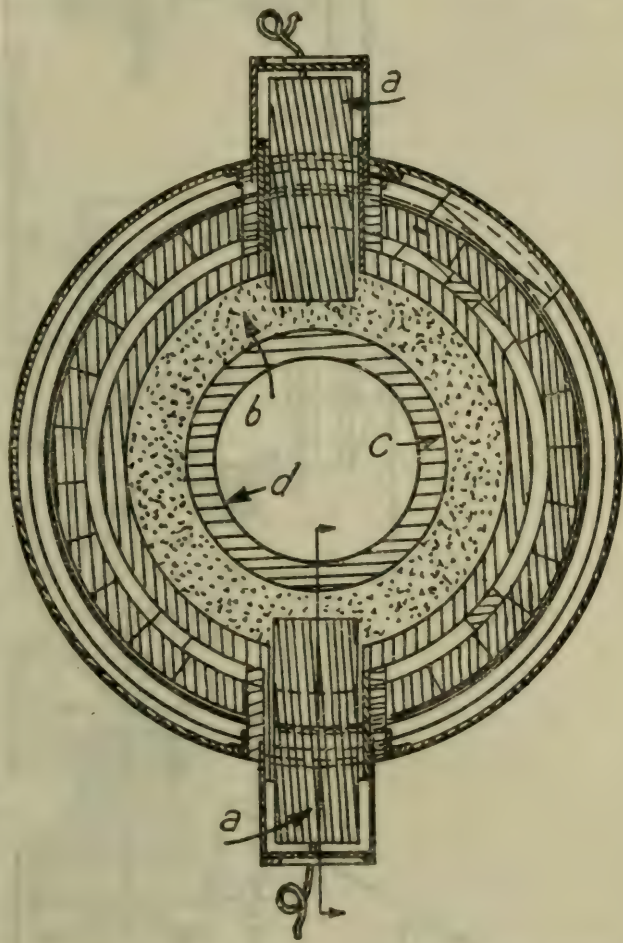


FIGURE 15.—Plan of electrodes and resistor trough of Baily furnace.

the trough between it and the furnace wall. Fairly free radiation is thus provided from all sides of the circular trough (see Pl. VI, A), although much of the radiation must be reflected by walls and roof before it can reach the hearth which lies below the resistor in the bottom of the furnace chamber. The Baily resistor has a radiating surface of more than 40 square feet. Now a granular resistor must have a fairly generous cross section; approximately 6 inches high by 8 inches wide for the inside dimensions of the trough are common dimensions, and with 2-inch walls the whole trough is about a foot wide. The resistor thus occupies a good deal of space, and as care is taken to allow free space outside the resistor the whole furnace becomes very large for the metal charge used in it, which in different

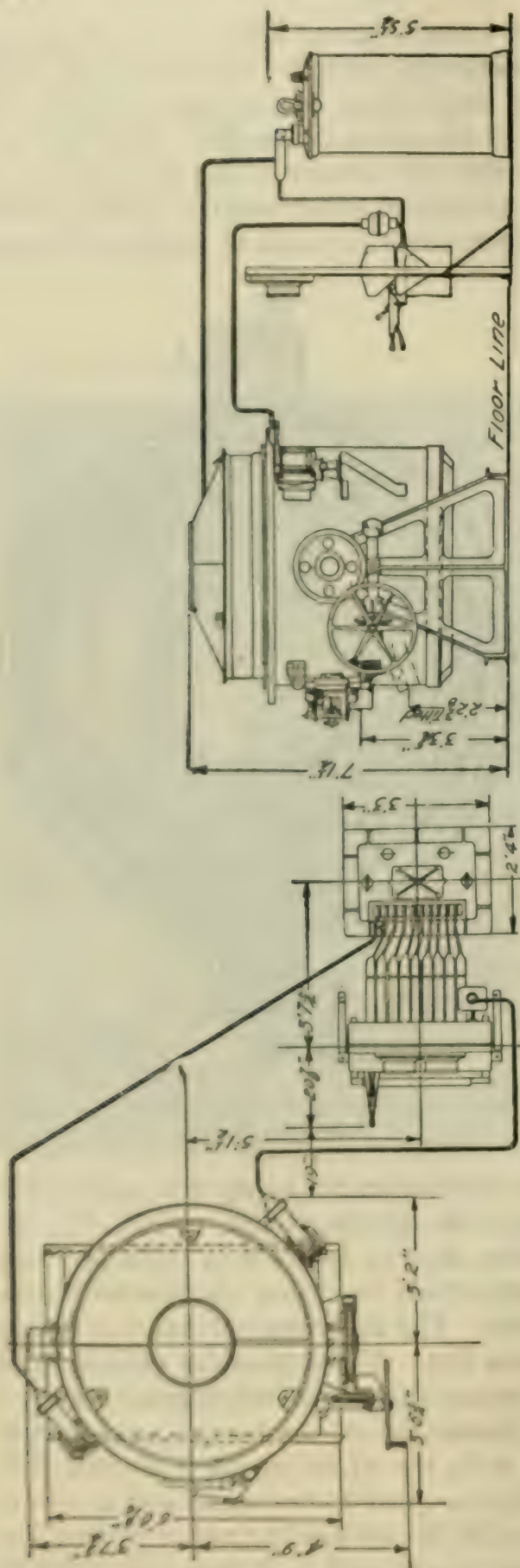


FIGURE 16.—Furnace, switchboard, and transformer layout for Baily furnace.

plants varies from 800 to 1,800 pounds, with an average of perhaps 1,200 pounds. The large amount of waste space within the furnace and the great wall volume and shell surface all tend toward lowering the thermal efficiency. The furnace also has a huge heat storage in the walls. These drawbacks are necessary evils, accepted in order to protect the resistor by allowing it free radiation. As a further precaution against overheating of the resistor, the power input of the 1,000 to 1,500 pound furnace is held very low, the rated capacity of the transformer supplied with the furnace being only 105 kw. The layout of transformer, switchboard, and furnace is shown in figure 16.

Baily²⁸ has written a paper describing this furnace, in the discussion of which paper Richards²⁹ points out that the figures given, calculated at a 90-kw. input, reach an efficiency of 64 per cent, not counting the power used at night when melting on a 10-hour basis,

²⁸ Baily, T. F., Resistance-type furnace for melting brass, Trans. Am. Electrochem. Soc., vol. 32, 1917, p. 155.

²⁹ Richards, J. W., Discussion, work cited, p. 104.

and a production on the best day's run given of 5,345 pounds of metal; but at a power input of 120 kw. the efficiency would be 74 per cent and the production would be 7,665 pounds. The Baily furnace is not supplied with a larger transformer and is not often run at a higher, more efficient power input, because the life of the resistor would be endangered and the reliability of the furnace would be decreased. It is very important that the furnace should not be overheated on account of the consequent injury to the resistor, as well as to the roof and walls, which have to reflect back so much of the radiant energy; Baily brass furnaces therefore are often equipped with a pyrometer in the roof, and the operator is rigidly instructed to reduce the power input when the roof reaches a certain temperature. The actual temperature depends on the location of the pyrometer. It may be placed through the roof to register the temperature of the chamber itself, or it may be embedded in the roof, where it will register a lower temperature. The furnaces are run at a temperature of 2,500° to 2,600° F. (1,375° to 1,430° C.) in the top of the chamber when the charge is poured at 2,000° to 2,100° F. (1,100° to 1,150° C.).

It can readily be seen that the large mass of brickwork gives a large heat storage and that the roof, walls, and resistor, being 500° F. (280° C.) hotter than the metal at the end of the heat, can continue the heating of the metal long after the power is cut off. Miller³⁰ states that it takes something like 15 minutes before the furnace begins to respond to a change in power input. The stored heat is so great that after running at full tilt all day the power can be cut down very low on the last heat of the day, the stored heat doing most of the work. This means that when the furnace is used on yellow brass, especially in rolling-mill work, where the metal must be poured nearly at its boiling point, if a delay occurs and the metal must be held in the furnace, the power must be at once cut off and scrap or gates added to the charge in order to keep the stored heat from heating the metal altogether too hot. One plant, operating on 70:30 brass poured at an average of 1,875° F. (1,025° C.), states that the first 200-pound ladle poured from an 800-pound heat averages 1,010° C. (1,850° F.) and the last 1,040° C. (1,900° F.) or higher.

Baily states³¹ that his furnaces "have an immense heat storage capacity in their refractory walls." It takes a good deal of energy to bring one of these furnaces to operating temperature. In a 10-

³⁰ Miller, D. D., The electric furnace as a medium for heating nonferrous metals: Jour. Am. Inst. Metals, vol. 11, 1917, p. 285; see also Benzinger, R. F., Are single-phase furnace loads profitable for the central station? The Electric Furnace, vol. 1, 1920, No. 3, p. 12.

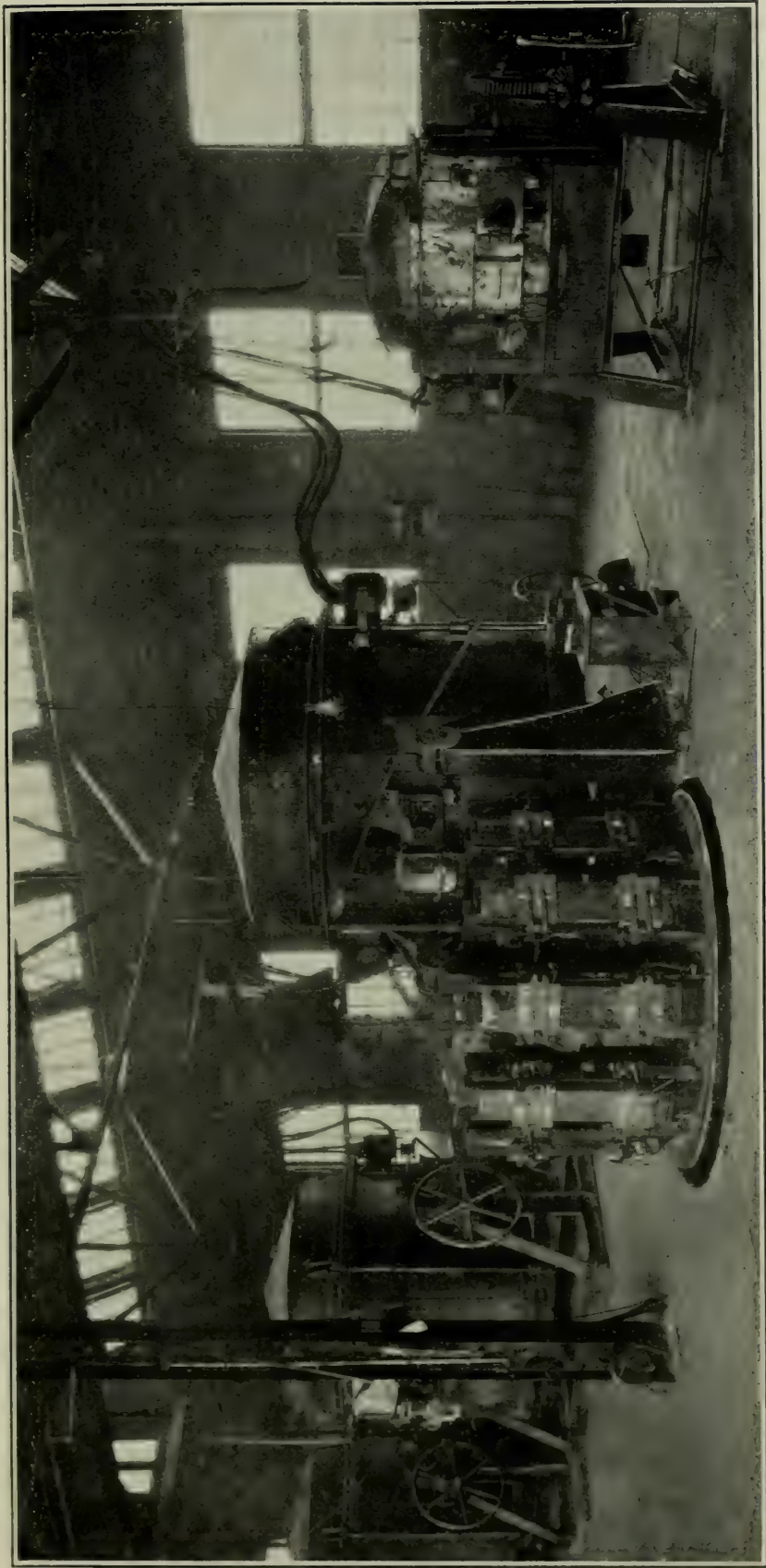
³¹ Baily, T. F., The resistance-type electric furnace: The Electric Furnace, vol. 1, No. 2, February, 1920, p. 15.

hour operation the first 16 tons of yellow brass melted in the Baily furnace installed at the plant of White & Bro. averaged 880 kw. h. per ton, including the power used in preheating the furnace. The sluggishness of the furnace means that it heats up slowly, as well as cools off slowly, and after cooling 14 hours it would take so long to bring it to full running temperature that production in a 10-hour melting day would be very low. Hence it is regular practice to have the night watchman throw the power on the furnace about 3 a. m. in order to have the furnace ready to melt at 6.30 a. m. The power used at night has to be paid for as well as that used while metal is in the furnace, so that no figures of power consumption for this furnace or for any furnace of a type that requires night heating should be given without also stating whether the night power is included.

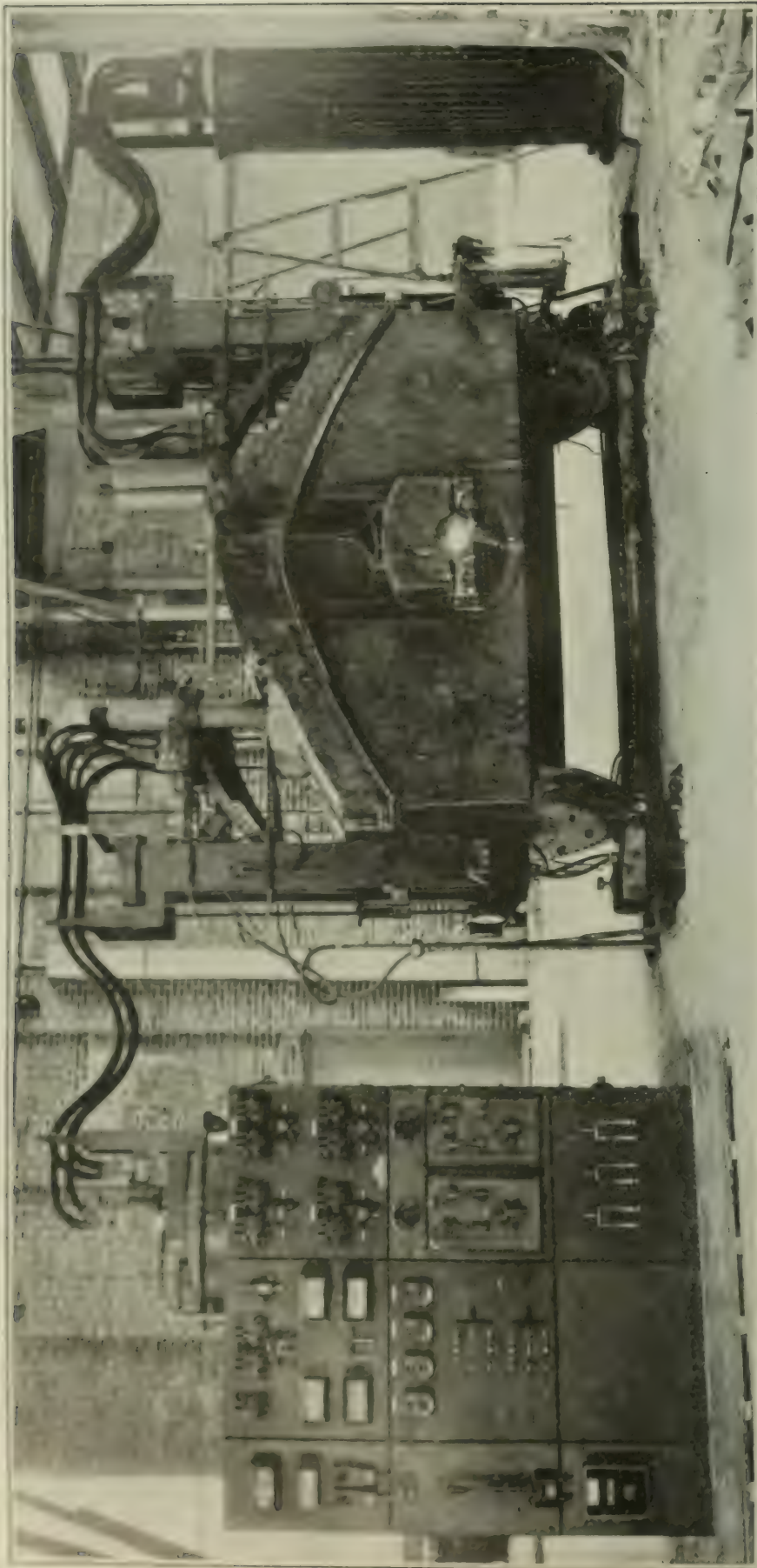
It follows that the furnace, though seldom so used in practice, is at its best on 24-hour operation and is under a decided handicap when used only on day shifts.

Besides the standard 105-kw. tilting furnace (see Pl. VI, *B*) mounted on trunnions—the type so far installed by most users—a nose-tilting type (see Pl. VII) of the same size has been designed for pouring direct into molds, one of which has been installed at the Washington Navy Yard, and a 300-kw. size has been designed, but no installations have yet been made. A 105-kw. “nose tilter” has been sold to Allen Everett Co., Ltd., of England.

A smaller, trunnion-mounted, tilting type of Baily furnace of 50 kw. rating, shown at the right in Plate VIII, was put on the market in 1919. This type held up to 500 pounds maximum, having a rectangular shell and a long oval hearth. It was heated by a single straight resistor trough located directly over the bath, supported at the ends. A few furnaces of this type were installed, but the life of the resistor trough was so short that its use was found impractical and it was withdrawn from the market, a round, 50-kw., 500-pound furnace of the same general design as the 105-kw. size being supplied instead. Since this has nearly as much wall area as the 105-kw. furnace, its losses in radiation will be nearly as great, and the lost heat will form a large proportion of the 50 kw. supplied. The efficiency of this size, therefore, may be expected to be very low. No operating figures for this size on brass are yet available, but the relative behavior of different sizes of this type of furnace may be seen from data on melting aluminum (No. 12 alloy): The 105-kw. size at the Dayton Engineering Laboratories Co., on 425-pound heats—length of working day not stated, but apparently about 8½ hours actual melting, plus 1 hour preheat—gave an output of about



BAILY FURNACES SET UP FOR DEMONSTRATION. TWO TRUNNION-TYPE 105-KW. FURNACES AT THE LEFT, A NOSE-TILTING 105-KW. FURNACE AND CASTING TABLE IN THE CENTER, AND THE OBSOLETE RECTANGULAR 50-KW. FURNACE AT THE RIGHT



A 2,500- POUND 400-KW. GENERAL ELECTRIC RECTANGULAR FURNACE.

1½ tons per day at 675 to 625 kw. h. per ton. The 50-kw. rectangular size at the plant of Landers, Ferry & Clark, on 150-pound heats, 9 hours actual melting, 4 hours preheat, gave an output of ½ ton per day at 850 kw. h. per ton. The net metal loss is given as 0.7 per cent.

Since the 105-kw. size runs at around 600 kw. h. per ton of brass on a 9-hour melting day, it would be expected by analogy with the results given above on aluminum that the 50-kw. size, working on brass, with a 9-hour melting day, would require around 750 kw. h. per ton.

One plant, melting red brass in the rectangular 50-kw. Baily furnace, on a 7-hour working schedule, the furnace being preheated at night, averaged three heats of 525 pounds, or about ¾ ton per day, at a total power consumption of 730 kw. h., i. e., about 900 kw. h. per ton. The gross metal loss is given as 1 per cent and the life of the resistor trough as only 100 heats.

The Baily furnace is also built in a stationary tapping type, with a hearth lying between two straight resistor troughs. One furnace of 500-kw. rating has been in use on aluminum, and one of 1,000 kw. has been used in melting down electrolytic zinc cathodes. A 600-kw. furnace of this type for brass has been designed, but none yet installed. All these furnaces are supplied with energy through a variable-voltage transformer having a number of taps on the secondary, to which connection is made by an oil switch operated by hand. Lehr³² has patented a system by which the regulation of such a furnace may be made automatic. Short³³ describes an automatic control as supplied by the Westinghouse Co. to 40 furnaces, each of 1,100 kv. a., for zinc smelting in Norway. (These are not Baily furnaces.) Hand control of the Baily furnace is simple, and it is doubtful if the application of an expensive automatic control system to the 105-kw. size would normally be justified.

METALLURGICAL RESULTS IN THE BAILY FURNACE.

METAL LOSSES.

Baily³⁴ cites some tests on yellow brass (68 per cent Cu, 32 per cent Zn) made up of half scrap, half new metals, in which the net metal loss, taken by weighing the charge, deducting the nonmetallic in the charge, and weighing the product, was 1.39 per cent when the zinc was added with the rest of the charge at the start of the heat and 0.56 per cent when it was added at the end in the usual way.

³² Lehr, E., U. S. Patent 1,320,071, Oct. 28, 1919.

³³ Short, P. B., Step-induction regulator for electric furnaces: *Trans. Am. Electrochem. Soc.*, vol. 37, 1920, p. 35; see also Pierce, R. T., U. S. Patent 1,367,089, Feb. 1, 1921.

³⁴ Baily, F. T., work cited.

In a test reported by one foundry on a leaded bearing bronze (79 per cent Cu, 16 per cent Pb, 5 per cent Sn, trace P) there was charged:

	Pounds.
Ingot	728
Gates carrying some sand	5,198
Lead	192
Copper	936
Tin	72
Total	7,126
Metal poured	7,009
Gross loss (1.63 per cent)	117

The foundry estimates that 26 pounds (5 per cent) of sand adhered to the gates, making the gross loss 91 pounds on 7,100 pounds metallic charged, or 1.28 per cent corrected gross loss. Ninety-two and one-half pounds of skimmings, from which it is estimated that 40 per cent, or 37 pounds metal, would be reclaimed were also obtained, making the net loss 54 pounds on 7,100 pounds of metallic charged, or 0.76 per cent. The furnace replaces an open-flame oil furnace and makes decided metal savings.

Other tests, cited in the advertising literature of the Electric Furnace Co. are as follows:

TABLE 28.—Results of runs with Baily furnace.

Material.	Metal charged.	Metal poured.	Loss.	Loss.
	Pounds.	Pounds.	Pounds.	Per cent.
Tallent brass, cast, forged forgings	23,429	23,361	78	0.30
Tallent brass, rolled	181,304	179,833	1,471	.81
Do	28,320	27,941	379	1.30
Phosphor bronze	35,733	35,686	87	.24
Do	6,033	5,991½	41½	.68

One plant reports that in regular operation the total metal loss in melting bronze of 89 per cent Cu and 11 per cent Sn in the Baily furnace, including all losses between charge and finished product, whether in melting or not, is 2.5 per cent. Another plant making an ordinary red brass from all scrap and borings declares that the net metallic loss, by test, is 1 per cent and is convinced that the furnace runs regularly at that figure. This plant takes care to plug and lute the spout and door tightly to avoid oxidation and volatilization. It asserts that on the material used the loss in coke fires can not be kept below 5 per cent in regular operation, though that figure can be surpassed on careful tests.

Another plant, running on 70:30 brass for sand castings made from scrap and borings, estimates the metallic loss to be 1 per cent

against about 5 per cent in coke fires. In still another plant which makes a cast yellow brass with about 20 per cent Zn, largely from scrap, the gross loss between dirty scrap and hot metal weighed in the ladle was 2.8 per cent on the first few heats, while the new hearth was becoming saturated, and fell on the next 20 tons melted to 1.25 per cent. It is estimated by this plant that there was 0.25 per cent dirt, oil, etc., in the scrap, and an additional 0.25 per cent would have been recovered had all the spillings been picked up. The true metallic loss therefore was not over 0.75 per cent. In coke-fired practice on this alloy the average net loss was said to be 3 per cent, and some actual tests showed 3.44 per cent.

UNIFORMITY OF PRODUCT.

The behavior of the furnace as regards metal losses is excellent, but is not so good as regards uniformity of composition of the product. Baily^{34a} gives figures for 30 heats of yellow brass (about 69 per cent Cu, 31 per cent Zn), the copper in which was determined by sampling the first and last bars poured from a 750-pound heat. The copper averaged 0.70 per cent higher in the last bar than in the first. In three heats there was no variation, in only five others was the difference below 0.25 per cent, in two between 0.25 and 0.50 per cent, in eleven it was from 0.50 to 1 per cent, in eight it was between 1 and 2 per cent, and one heat showed a variation of from 68.67 per cent in the first bar to 70.71 per cent on the last, or 2.03 per cent.

These figures were obtained on a test of one of the first Baily furnaces commercially installed, made by the makers of the furnace and not by the rolling mill. The metal was poured colder than it would have been had a regular caster done the pouring, and the importance of stirring was evidently not understood. The figures do not mean that uniform metal can not be poured from the Baily furnace or from other hearth furnaces similarly heated by radiation from above, but they do indicate a tendency to imperfect mixing and show that it is important for the metal to be thoroughly stirred before pouring. At the plant where these tests were made differences of more than 2 per cent in copper between the first and the last of the pour have been noted even with careful stirring, and uniformity is considered harder to obtain than in crucible practice.

According to Hess,³⁵ in melting steel in the Heroult direct-arc furnace there is little circulation, and heavy alloys are likely to settle, causing segregation and lack of homogeneity, which, he says, should be guarded against by systematic and vigorous stirring. As there is even less tendency toward circulation in furnaces like the Baily

^{34a} Baily, T. F., Work cited, p. 291.

³⁵ Hess, H. L., Electric furnaces as applied to steel making: Mech. Eng., vol. 41, 1919, p. 245; Chem. Abst., vol. 14, 1920, p. 16.

that melt by radiated heat than in direct-arc types, Hess's advice appears worth heeding in the operation of brass furnaces that do not stir the metal automatically, as well as in the operation of steel furnaces.

QUALITY OF PRODUCT.

The quality of the metal, from the testimony of three different users, is no worse and no better than good metal from coke-fired crucible furnaces. If careful attention is paid to stirring, the metal is thought to average more uniform, merely because the use of a larger charge than in a crucible tends to even up its regularity in composition of scrap used. In one case the metal was thought to machine more easily.

ADAPTABILITY.

The furnace can be drained completely and successive heats of different alloys made. On account of the necessity for keeping down the chamber temperature and the power input, in order to safeguard the resistor, the furnace will be less efficient on and less adaptable to the alloys that have to be poured at a high temperature. Few Baily furnaces regularly produce metal that would be poured above 1,150° C. (2,100° F.).

The furnace will melt any ordinary brass or bronze (probably not Monel metal), but is at its best on yellow brass and on red brasses and bronzes that do not have to be poured too hot.

Two different plants report that on charges of all yellow borings, especially if dirty and oily, the Baily furnace does not give satisfactory results, because such charges require too much stirring and riddling. Charges containing not over 50 per cent yellow borings can be handled.

Although criticizing the Baily furnace for low efficiency—that is, for excessive power consumption per ton—one refining plant asserts that the Baily furnace should have a use in a refining plant in handling light or “irony” brass, as the melt can be skimmed to remove iron without interrupting the current.

RELIABILITY.

The reliability of some of the early installations of Baily furnaces was affected by the inability of the transformers to take their rated load without heating up, but this defect has been overcome.

The life of the lining and roof (corundite brick) is good, provided care is taken to keep the chamber temperature below a safe point. In one furnace, supplied with a pyrometer in the roof, that was inspected after 18 months operation and after the melting of more than 1,000,000 pounds of 70:30 brass, the lining was still in good shape. The resistor trough had to be renewed after about 250,000 pounds had been melted.

Another furnace, on 16-hour operation on red brass, had required no repair in melting about 600,000 pounds. Another, on 9-hour operation on yellow brass, had required one new hearth lining in melting 350,000 pounds, the hearth probably being damaged by throwing in heavy ingots, but no other repair besides patching the spout. The hearths are usually rammed up from carborundum fire sand, plus fire clay and water glass or some similar mixture.

One user of the Baily furnace, melting a leaded bronze with 10-hour operation, concluded that the hearth and resistor trough must be replaced after melting 1,000,000 pounds, and calculated the up-keep of the furnace, at 1919 prices, to be 50 cents per ton. Still another user has said that the trough averages a life of 250,000 pounds, but that with greater care in operation this figure can probably be doubled.

Other users had great trouble with resistor troughs when they were rammed up in a form inside the furnace from carborundum fire sand with a water-glass binder, the troughs often failing after only a very few heats; sectional troughs are now molded up and baked by the makers and sent to the user to be set up like so much brickwork. These appear to be giving good service.

Electrodes are usually replaced whenever a trough is replaced. The granular resistor material—electrode carbon broken to $\frac{3}{8}$ -inch or $\frac{1}{4}$ -inch mesh—slowly burns away and must be replenished, about 25 pounds being normally added every Sunday according to one user and at the rate of 10 pounds per day according to another. This granular carbon costs in the neighborhood of 5 cents per pound. The resistor carbon used must be as free as possible from ash or the ash will gum up the resistor, interfere with the flow of current, and endanger the trough.

In some plants where much skimming and rabbling has been done the piers (usually silica brick or corundite) have occasionally been damaged by the operator's careless poking. Generally speaking, the reliability of the furnace, when operated under pyrometric control, is good.

RATES OF PRODUCTION AND THERMAL EFFICIENCY.

As the rate of production and the thermal efficiency are closely related, they will be considered together.

Baily³⁶ has given figures on a week's run of a furnace at the Baltimore Copper Smelting Rolling Co. on 68:32 brass which show the following averages:

Average number working hours per day-----	8 $\frac{1}{2}$
Average number heats per day-----	5 $\frac{1}{2}$
Average charge-----pounds--	752
Average kw. h. per heat (not including night heating)-----	128.4

³⁶ Baily, T. F., Resistance-type furnace for melting brass: Trans. Am. Electrochem. Soc., vol. 32, 1917, p. 155; Brass World, vol. 13, 1917, p. 337.

While not stated in this paper both Mr. Baily and the superintendent of the plant³⁷ state that power was kept on the furnace all night at the rate of 44 kw.

This gives:

Average kw. h. used at night (15½ hours), at 45 kw., per night.....	671
Average kw. h. used in day (8½ hours), at 77 kw., per day....	685
Total kw. h. per 24 hours.....	1,356
Average output, 8½-hour working day.....pounds...	4,011
Average kw. h. per ton.....	675

In the regular operation of this furnace on 70:30 brass, poured at 1,925° C. (1,875° F.), with power kept on all night at 45 kw., the plant reported an output of 4,100 pounds (five heats, 820 pounds), with an average kw. h. consumption of 650 per ton. Individual heats at the end of the day, when the furnace was fully hot, were made with 130 kw. h., that is, at the rate of 310 kw. h. per ton for continuous 24-hour operation. With the furnace fully hot, copper poured at 1,200° C. (2,200° F.) required 333 kw. h. per ton, with an average power input of 100 kw. The rate of production on 24-hour operation would be about 15,000 pounds brass a day when the furnace is run at a 77-kw. input and 12,000 pounds copper a day when running at a 100-kw. input. The transformer supplied with this early furnace would not give 100 kw. steadily without undue heating.

This particular furnace is no longer in operation, the plant having gone out of the brass business entirely. The company asserts³⁸ that the furnace can not be considered for the melting of copper in competition with the regular reverberatory furnaces taking 200 to 250 tons per charge; though the application of the principle involved in the melting of large charges is interesting, it introduces too many problems for serious consideration.

A Baily furnace was tried but discarded by the Bridgeport Brass Co.

Another user gives the following figures for bronze (89 per cent Cu, 11 per cent Sn) poured at 1,150° C. (2,100° F.). Average weight of charge, 800 pounds; seven heats in 10 hours, 5,500 pounds output per day; power used, 1,100 kw. h. in 10 hours; average output, 110 kw., 550 kw. h. in 14 hours (night); average input, 39 kw.; total kw. h., 1,650, or 600 kw. h. per ton.

Another plant working on 70:30 brass made from scrap and borings for sand castings reports, on 9-hour operation (6 a. m. to 4 p. m.), power input held at 100 to 105 kw. (power off eight minutes while pouring) with night heating at about 75 kw. aver-

³⁷ Personal communications.

³⁸ Reese, E. W. Personal communication, Jan. 10, 1920.

age from 2.30 a. m. to 6 a. m., week days, except Saturday, and from 6 p. m. Sunday to 6 a. m. Monday; the output can be brought, as a maximum, to five heats of 1,500 pounds each. The average over-all power consumption is said to be 425 kw. h. per ton.

One man operates two furnaces in this plant by staggering the operation of the two furnaces, so that two heats are not ready to pour at the same time. The charges are brought to him and the metal taken away for him.

At another plant, operating two 8-hour shifts on leaded bronze, the furnace being preheated four hours besides—that is, power being off only four hours per day—the average output in the 16-hour melting period is 4 tons, and the power consumption runs from 500 to 575 kw. h. per ton.

Still another plant, operating two 10-hour shifts, with three hours preheating, on red brass, gets an average output of $4\frac{1}{2}$ tons, though up to $6\frac{1}{2}$ tons have been obtained. The power consumption averages 550 kw. h. per ton.

One plant, melting 60:40 brass 24 hours a day, gets an output of 8 tons per day at 310 kw. h. per ton, while another has obtained a power-consumption figure on yellow brass, 24-hour operation, of 264 kw. h. per ton, but states that this is lower than can be expected as an average.

One plant, making sand castings of yellow brass (20 per cent Zn) from scrap got six heats of 1,000 pounds in 10 hours by using 400 kw. h. from 2 a. m. to 6.30 a. m. and 1,100 kw. h. from 6.30 to 4.30, or 1,500 kw. h. for 3 tons, or 500 kw. h. per ton. This figure is rarely reached because of delays in pouring, etc., 550 kw. h. being more common and 600 kw. h. the average. The best possible figure on 10-hour operation at this plant is thought to be 450 kw. h. per ton.

At another plant, on a test to see what maximum output could be made on an alloy of 79 per cent Cu, 5 per cent Sn, 16 per cent Pb, trace P, charge 73 per cent gates, 10 per cent ingot, 17 per cent new metal, the following figures were obtained:

TABLE 29.—*Test of Baily furnace on leaded bronze.*

Heat No.	Time.	Weight of charge.	Kw. h. used.
		Pounds.	
Preheat.....	2.00 a. m. to 6.30 a. m.....	(a)	375
1.....	6.30 a. m. to 8.00 a. m.....	1,102	200
2.....	8.00 a. m. to 10.00 a. m.....	1,220	200
3.....	10.00 a. m. to 11.40 a. m.....	1,200	175
4.....	11.40 a. m. to 1.00 p. m.....	1,202	175
5.....	1.00 p. m. to 3.00 p. m.....	1,200	175
6.....	3.00 p. m. to 5.00 p. m.....	1,202	175
Total.....		7,126	1,475

a Empty.

Average kw. h. per ton	413
Average time to charge and pour	minutes 20
Average power input (preheating, 4½ hours)	kw. h. 83½
Average power input (working time, 10½ hours)	kw 105

The last heats are at the rate of 290 kw. h. per ton on 24-hour operation. The transformer temperature rose from 35° C. at 2 a. m. to 59° C. at 5 p. m. On another day's run, using 1,500-pound charges of leaded phosphor bronze, the following result was obtained:

TABLE 30.—Test of Baily furnace on leaded bronze, 1,500-pound charges.

Heat No.	Time.	Weight of charge.	Kw. h. used.	Kw. h. input.
	H. M.	Pounds.		
1	2 20	1,516	b 375	105
2	2 0	1,509	252	126
3	1 35	1,505	203	128
4	1 30	1,503	206	137
Total	7 25	6,033	c 1,282	122

^a Figures taken from advertising literature of Electric Furnace Co. Power used on preheat not given, estimated from the preheating test. The last two heats indicate 205 kw. h. per 1,500 pounds, or 275 kw. h. per ton on the same operation, but partly on stored heat from the lining.

^b 375 kw. h. per ton.

A recent account²⁹ of the operation of a Baily furnace on yellow brass (75 per cent Cu, 20 per cent Zn, 4 per cent Pb, 1 per cent Sn), poured at 1,200° C. (2,200° F.) declares that by preheating from 3.30 a. m. to 6 a. m. four heats of 1,500 pounds each are taken off by 3.30 p. m. One more heat could be taken by running to 5 p. m. The power consumption over a month's run (70 tons) was 572 kw. h. per ton. The furnace is said to give best results if run at 120 kw., a higher power input shortening the life of resistor trough and roof and a lower one increasing the power consumption per ton. The resistor trough and hearth last about six months; that is, for the melting of some 400 to 450 tons.

In a comparison of melting costs between crucibles and the electric furnace the upkeep of the Baily furnace is put at 60 cents per ton. The labor cost for electric melting is half what it was for crucible melting, and the metal loss is reduced from 5 per cent to 1 per cent. The costs are given as \$19.20 per ton in crucibles (of which \$6.40 is due to the loss of 4 per cent more zinc) and as \$15.20 in the electric. Power cost 1.41 cents. per kw. h., or \$8.06 per ton. It is the saving in metal that makes the furnace economical. It should be noted that this cost tabulation does not include interest and depreciation on the investment in the furnace.

The red brass melted at this plant is still melted in crucibles, because the metal loss in the crucibles is only about 2 per cent, so that

²⁹ Anonymous, Electric melting shows economy: Foundry, vol. 47, 1919, p. 845; Anonymous, Operating data on electric brass furnace: Elec. World, vol. 75, 1920, p. 11.

the electric furnace would save only 1 per cent and the cost balance, which is swung for the electric on yellow brass solely by the saving in metal losses, is against the Baily furnace on red brass.

FURNACE OF ANACONDA COPPER MINING CO.

At Great Falls, Mont., a standard Baily 105-kw. furnace is installed in the brass foundry of the Anaconda Copper Mining Co. This firm uses large amounts of electric power generated by water power for general purposes, for the operation of ferro-alloy furnaces, and for the electrodeposition of zinc. When hydroelectric power is bought under such circumstances it is usually paid for, not by the kw. h. actually used, as is the case in most brass foundries, but by the kilowatt year; that is, by the most simple form of power contract a certain amount a year is paid for each kilowatt the plant in question is equipped to draw from the hydroelectric station.

After the furnace at Great Falls had been used intermittently for 15 months the lining was still in excellent condition, one resistor-trough replacement having been made and the second being nearly ready for renewal. The melting rate, after the furnace is fully hot, is 1,800 pounds in $3\frac{1}{2}$ hours; that is, 515 pounds per hour on the basis of continuous operation. As high as 2 tons have been charged into the furnace at one time. The metal loss is under 2 per cent.

The power consumption averaged 2,900 kw. h. per ton during four months' intermittent operation, in which 42.4 tons were melted. It is said that if the furnace were operated continuously 24 hours per day it could probably equal the guarantee, made on the basis of continuous operation, of 400 kw. h. per ton. The furnace is said by the Anaconda Co. to be very satisfactory for their foundry work. The work is intermittent, only about 15 tons of metal being melted per month, on the average, and only about 10 tons per month in the period on which the figures of power consumption were computed.

Power is kept on the furnace all the time, the increased power consumption being offset by the time saved in bringing this sluggish type of furnace up to working temperature if it is allowed to cool.

At the rate of 515 pounds per hour, the four months' melt of 84,800 pounds would take only 165 hours out of 2,880, or 6.6 full 24-hour days out of 120 days.

To keep the furnace hot all the time would require an average input of about 40 kw. for the whole 2,880 hours, and if the power input was raised by 50 kw. to an average of 90 kw. during the 165 hours of actual melting the power consumed would be $(40 \times 2,880) + (50 \times 165)$, or 123,650 kw. h. used to melt 84,800 pounds, or 2,900 kw. h. per ton.

Had this amount of power been paid for on the kind of a power contract used by most purchasers of a single Baily furnace it would probably cost about 1.4 cents per kw. h., or about \$40 per ton for power alone.

On so large a connected load as that at Anaconda, where there would be several times 100 kw. leeway between the connected kw. of the high-tension transformers and the average load, it would make no difference in the actual cost of power whether the Baily brass furnace were run or not. Even for cost accounting it might be calculated that only the 40 kw. used all the time should be charged against the furnace if the foundry took care to do the actual melting at a time when the rest of the plant was not drawing its full load.

Forty kw. for 4 months at, say, \$25 per kw. year would cost \$333.33 for 42.4 tons, or \$7.85 per ton on a melt of 10.6 tons per month, a figure which is less than the \$8.06 per ton in the furnace last commented on, which used 572 kw. h. per ton at \$1.41 per kw. h. on a melt of 70 tons per month.

All these data tend to show that where power is high the Baily furnace should be used for melting 16 to 24 hours per day, as it is at a disadvantage on account of its high-heat storage on 10-hour melting; where power is extremely cheap, it can be satisfactorily used on 10-hour melting or even as intermittently as the Anaconda installation. The resistor troughs have had to be replaced twice in 21 months, while melting an average of 15 tons per month or, say, 157½ tons average per trough, on this intermittent service.

Omitting the Anaconda furnace on account of the unusual operating conditions, the commercial results on the 105-kw. Baily furnace can be summarized as in Table 31.

TABLE 31.—Summary of Baily furnace operation.

Agency.	Firm.	Kind of operation on which figures are based.	Hours furnace pre-heated per day.	Hours furnace used per day in actual melting.	Weight of charge.	Output per day.	Kw. h. per ton.
					Pounds.	Tons.	
Yellow brass	Baltimore Copper Smelting & Rolling Co.	Average.....	15	9	800	2	650
Do.	McRae Roberts.....	Best.....	3½	9	1,500	3½	425
Do.	Michigan Smelting & Refining Co.	do.....	0	24	(b)	(b)	c 264
20-40	East Indian Copper Products Co.	Average.....	0	24	.....	8	310
Steel, 25 per cent steel	Hayes Manufacturing Co.	One month, 70 tons.	2½	9½	1,500	3	572
Soft brass	Capital Brass Co.	Best.....	0	16	1,500	d 6	(b)
10-15-20-25-30-35-40-45-50-55-60-65-70-75-80-85-90-95-100-105-110-115-120-125-130-135-140-145-150-155-160-165-170-175-180-185-190-195-200-205-210-215-220-225-230-235-240-245-250-255-260-265-270-275-280-285-290-295-300-305-310-315-320-325-330-335-340-345-350-355-360-365-370-375-380-385-390-395-400-405-410-415-420-425-430-435-440-445-450-455-460-465-470-475-480-485-490-495-500-505-510-515-520-525-530-535-540-545-550-555-560-565-570-575-580-585-590-595-600-605-610-615-620-625-630-635-640-645-650-655-660-665-670-675-680-685-690-695-700-705-710-715-720-725-730-735-740-745-750-755-760-765-770-775-780-785-790-795-800-805-810-815-820-825-830-835-840-845-850-855-860-865-870-875-880-885-890-895-900-905-910-915-920-925-930-935-940-945-950-955-960-965-970-975-980-985-990-995-1000	Test.....	4½	10½	1,200	3½	413	
Do.	St. Louis Brass Co.	Average.....	4	16	1,500	4	500 to 575
Do.	Lucas Foundry Co.	do.....	11	10	800	2½	600
Soft brass	Lawrence Injector Co.	do.....	3	20	1,500	f 4½	550

a Melted ground in 1200° C.

b Not melted.

c This figure is said to be lower than can be expected as an average.

d (Output given in tons).

e Melted ground in 1200° C.

f The resistor troughs have been put out in two 16-hour shifts.

The standard Baily furnace rated at 105 kw. is thus seen to produce, on 10-hour operation, on metal poured at or below $1,150^{\circ}\text{C.}$, from 500 to 800 pounds per hour, $2\frac{1}{2}$ to 4 tons per day, and to use 425 to 600 kw. h. per ton. On 24-hour operation it would produce 6 to 10 tons at 275 to 350 kw. h. per ton. These variations depend partly on the pouring temperature needed and on the rate of power input, but even more so on the efficiency of operation and the speed of charging and pouring.

It has been found, in the practice of one plant, highly essential to operate the Baily furnace without a slag. If a dirty charge is used containing a lot of nonmetallic material, such as sand adhering to gates, so that as soon as the metal is fluid, it becomes covered with a layer of fluid or crusty slag, the furnace should be opened and the slag scraped off. If the slag or crust is left on it prevents the rapid absorption of heat reflected on it by the roof, slows up production, and tends to require running the roof too hot. It acts, in baffling the flow of heat, much as a crucible wall would act.

ELECTRICAL CHARACTERISTICS.

The single-phase 105-kv. a. transformer is usually arranged to give 55 to 110 volts by 5-volt steps. The furnace, in normal running, after it is heated up, takes about 80 volts, 1,300 amperes. Control is obtained by a selective oil switch to the transformer taps. Continual changing of voltage is not necessary, but the watt meter must be watched in order not to allow the power input to rise or to fall off too much, as the furnace has a general drift toward taking a higher or a lower power input, with any impressed voltage, according to whether the resistor temperature is rising or falling.

The power factor is close to unity, and there are no sudden surges on the line, the variation being between zero and 100 kw., approximately, when the switch is opened and closed to change the voltage.

COST OF THE BAILY FURNACE.

The prices of the Baily furnace complete in April, 1920, were as follows: 105-kw., about \$9,400; 75-kw., about \$6,500; 50-kw., about \$5,000.

BAILY FURNACES MELTING ALLOYS OTHER THAN BRASS OR BRONZE.

The Lumen Bearing Co. uses one of the 105 kw. regularly and another intermittently on Lumen metal, a bearing alloy of about 85 per cent Zn, 10 per cent copper, 5 per cent Al. This is poured at about 700°C. ($1,300^{\circ}\text{F.}$). An average of $5\frac{1}{2}$ heats of 1,000 pounds each is obtained per 10-hour working day, 660 kw. h. being used during the

day and 330 during the night to keep the furnace hot. The furnace now regularly used for Lumen metal was bought secondhand, having been tried out by the Aluminum Co. of America for making up aluminum alloy ingot from pig aluminum and discarded, largely, it is understood, because of its being too small in size for such purpose. A 75-kw. Baily furnace has recently been sold to the Norsk Aluminum Co., Norway, for melting aluminum. No data are available on this.

Miller⁴⁰ describes a 500-kw. tapping-type Baily furnace used for remelting aluminum pig poured at about 850° C. (1,560° F.). It has two straight resistors, one on each side of the hearth, which holds 3 to 4 tons of aluminum. Such a furnace may be made to take three-phase current if desired.⁴¹

The furnace was operated 24 hours a day; capacity of production was 20 to 24 tons. Since it is rated at 500 kw., it could use around 12,000 kw. h. per day, or at the rate of about 500 kw. h. per ton.

Miller, however, claims that 265 kw. or 64,000 kw. h. per day, 320 kw. h. per ton, will do the work on 24-hour operation. From the data of Richards⁴² it appears that to raise aluminum to about 700° C., or 150° C. below the temperature given by Miller, will take 300 kw. h. per ton, at 100 per cent thermal efficiency.

Laschitschenko⁴³ shows that at about 700° C. the total heat in the molten aluminum is about 300 calories per gram; that is, about 320 kw. h. per ton. The presence of 8 per cent of copper in the usual No. 12 alloy would reduce the heat needed somewhat, but it is evident that, roughly, 300 kw. h. per ton of No. 12 aluminum represents 100 per cent efficiency. In a furnace of 60 per cent efficiency 500 kw. h. per ton would actually be required. It therefore seemed very doubtful if the 320-kw. h. figure were correct. Hence the matter was referred to the superintendent of the plant operating the furnace, who replied as follows:⁴⁴

Under best conditions and continuous operations we can melt 1 ton of aluminum per hour with a power consumption of slightly less than 500 kw. per ton.

We have had some difficulty with the furnace due to inherent defects or objectionable features in the design. The resistor troughs are a source of trouble, failing frequently. The transformer supplied with this furnace was built by the Electric Furnace Co., and has given us some trouble. It is

⁴⁰ Miller, D. D., The remelting of aluminum pig in the electric furnace: *Chem. and Met. Eng.*, vol. 10, 1918, p. 231.

⁴¹ See Baily, T. E., and Cope, E. T., U. S. Patent 1,322,749, Nov. 25, 1919.

⁴² Richards, J. W., Electric power required to melt metals; *Trans. Am. Brass Foundry Assn.*, vol. 4, 1910, p. 91.

⁴³ Laschitschenko, F. S., Specific heat of aluminum: *Jour. Russ. Phys. Chem. Soc.*, vol. 16, No. 56, 1914, p. 211; see also Martin, P. D., Aluminum and its light alloys: *Bureau of Standards Cir.* 70, 1919, p. 27; see also Whist, E., Meuthen, A., and Durrer, R., Thermal constants of technical materials, *Instrumentenkunde*, vol. 39, 1919, p. 294; *Chem. Abstr.*, vol. 14, 1920, p. 1241.

⁴⁴ Vail, A. E. personal communication, Jan. 21, 1920.

"Number One" in their series and I am inclined to think could be considerably improved upon in design. We purchased this furnace primarily for making high zinc alloys of aluminum. We found that there was a noticeable decrease in the zinc losses over an oil fired or coal fired open hearth furnace. On the regular run of aluminum we could see no appreciable decrease in the melting loss. It was only in the case of zinc alloys that this difference was appreciable.

Our operating conditions are such that we could not keep the furnace in continuous operation. It has a very high heat capacity and requires a good deal of power to bring the furnace up to the proper operating temperature. When operated intermittently this is a decided drawback, since a large proportion of the power used is consumed in heating up the furnace. Over a period of time we found that under such conditions the power consumption was approximately 700 kw. per ton of metal melted. As a consequence we have practically abandoned the use of this furnace for melting aluminum. At the present moment we are seriously considering rebuilding the furnace for use as a pre-heating furnace for heating ingots for the rolling mill. The furnace has the decided advantage of close heat control and when operated at temperatures in the neighborhood of 1,000 to 1,200° F. it will stand up and give good service for a considerable period of time. We have an annealing furnace operating under such conditions which is giving very satisfactory results, but we can not say that we have been well satisfied with the performance of the melting furnace.

In a test, not made primarily for taking the figures of power consumption, on a standard 105-kw. Baily furnace, which was attended by a representative of the bureau, the furnace had been kept hot for some 12 hours beforehand, a power input of about 30 kw. being used in that period. The roof temperature at the start was 1,780° F. (970° C.); 100 pounds of No. 12 alloy (92 per cent Al, 8 per cent Cu) were melted and raised to 850° C. in 1 hour and 25 minutes, the roof temperature then being 1,825° F. (995° C.).

The furnace was run at about 40 kw. The power was then cut off, some metal poured, and the furnace left without power for 1 hour and 10 minutes, when the roof temperature was 1,850° F. (1,010° C.) and the metal was at 910° C., showing the great heat storage of the furnace. The power was then put on again, 50 pounds more of the alloy added, more metal was then poured, and after 1 hour and 40 minutes the charge was at 980° C.

In the whole 4 hours and 25 minutes, 192 kw. h. were consumed in melting and superheating 150 pounds of the alloy, in supplying radiation losses while the furnace was held at about the temperature required in melting aluminum regularly, and in heating the furnace, at the end, to somewhat above the initial temperature. The actual melting of the aluminum would take some 22 kw. usefully applied. Hence 170 kw. supplied the radiation losses for about 4½ hours. If it thus takes some 40 kw. to hold the furnace at the proper temperature without doing work, a 100-kw. furnace should utilize about 60 kw.; that is, should melt about 400 pounds per hour, as 300 kw.

usefully applied theoretically melts a ton. We should then expect on 24-hour operation that the 100-kw. Baily furnace would use 500 kw. h. per ton of aluminum and that on 10-hour operation it would require at least 600 kw. h. per ton.

Figures have already been given on the performance of the 105-kw. Baily furnace, showing 675 to 625 kw. h. per ton, and on the rectangular 50-kw. furnace, showing 850 kw. h. per ton, both on a 9-hour melting day. The net metal loss on 105-kw. furnace, melting No. 12 alloy, was estimated, but not actually determined, at 0.3 per cent, and the average net loss in the 50-kw. furnace was 0.7 per cent.

BAILY FURNACES FOR MELTING ZINC.

A 75-kw. Baily furnace has recently been sold to the Ilen Smeltwerk, of Norway, for melting zinc. No operating data are available.

The 1,000-kw. tapping-type furnace installed by the Anaconda Copper Mining Co., for melting electrolytic zinc cathodes is claimed to operate, on 24-hour service, at 75 kw. h. per ton. In January, 1918,⁴⁵ out of 5,112,335 pounds melted, 4,846,710 pounds were poured, the dross being 5.20 per cent. In four days in January, 1919,⁴⁶ 1,115,580 pounds were melted and 1,088,397 pounds poured, or a loss of 2.40 per cent.

The Anaconda Copper Mining Co. states⁴⁶ that the life of the resistor troughs in the zinc furnace is about three to four months; that the most economical tonnage of the furnace is 75 tons per 24 hours, the power consumption 100 kw. h. per ton, and that the Baily furnace is not considered a success for melting zinc cathodes, its use having been discontinued in favor of a coal-fired reverberatory, which is cheaper and makes less dross. A net recovery of practically 100 per cent of the zinc charged was made, but it was desirable to avoid the necessity of having to recover the metal from the dross, which averaged 6.5 per cent. The General Electric type and the Ajax induction-type furnaces are also said by the Anaconda Copper Mining Co. to be unsatisfactory for melting zinc.

Later reports⁴⁷ give fuller reasons for the failure of the electric furnace on zinc cathodes.

The cathodes form dross in melting in any furnace, and the blanket of dross prevents efficient transfer of heat to the charge in the electric furnace. To get anywhere near the rated production of the furnace (170 to 200 tons per day) the rate of energy supply must be so rapid and the resistor temperature so high that there is volatilization of zinc over 3½ per cent (about 6 to 7 tons per day). At a production

⁴⁵ Data from advertising literature, Electric Furnace Co.

⁴⁶ Anaconda Copper Mining Co. private communication, Dec. 16 and 22, 1919.

⁴⁷ Lohr, F., Froh, F. E., Elton, J. O., and Caples, R. B., Electrolytic zinc plant of Anaconda Copper Mining Co., Mining and Metallurgy, Bull. No. 1,028, 1920, p. 34.

rate of only 100 tons per day the resistors must run at so high a temperature that their life is too short. At 70 tons per day—that is, at a low rate of power input, so that heat conduction through the charge can prevent surface overheating and volatilization and so that the resistors do not run so hot—the furnace compares favorably, metallurgically, with coal-fired reverberatories, but the item of interest on investment at the low rate of production is so high as to make the furnace uneconomical.

A 50-kw. nose-tilting Baily furnace for melting silver has recently been sold to Johnson, Matthey & Co. (Ltd.), London.

MELTING CAST IRON AND STEEL IN THE BAILY FURNACE.

Experimental melting of cast iron has also been done in the Baily furnace.⁴⁸

It is also stated⁴⁹ that in a Baily furnace in which the usual hearth had been given an inner lining of magnesite 1,000 pounds of boiler-plate scrap was melted in seven and one-half hours, with the furnace running at about 90 kw., the heat being started with the furnace at full steel-melting temperature. It took about 75 kw. to hold the empty furnace at this temperature. It is argued from this test that high-speed steel can be handled in the Baily furnace.

The rate of melting is very slow, and if it be increased by raising the power input the life of the resistor trough would undoubtedly be very short. It is doubtful if the resistor trough would stand up long enough to make the furnace practical on tool steel even at the usual low rate of power input used on brass on account of the small leeway between the furnace temperature and the temperature at which the resistor trough fails.

SUMMARY ON BAILY FURNACE.

The standard 105-kw. Baily furnace is said by the makers to be capable of melting 2:1 yellow brass with 400 kw. h. per ton, 50 cents per ton furnace upkeep, and 1 per cent net metal loss. According to reports from users, it appears that with careful operation of the furnace this statement is correct, but that the figure of 400 kw. h. needs amplification. It can be reached by operating 16 hours per day, or lowered by operating 24 hours per day, but it would be difficult, if not impossible, to reach it in regular 10-hour operation.

Working conditions, as to coolness, cleanliness, and convenience are good, as are also the reliability and refractory life. Its electrical characteristics are satisfactory; it is one of the simplest and easiest of furnaces to operate; it gives a low metal loss, and most of its

⁴⁸ Anonymous, Melting cast-iron scrap: *Iron Age*, vol. 107, 1921, p. 1686.

⁴⁹ Anonymous, Melting steel in a nonferrous electric furnace: *Iron Age*, vol. 108, 1921, p. 472.

users consider that it shows a decided saving over the fuel-fired furnaces it has replaced. A dozen firms have each installed more than one Baily furnace.

The furnace is flexible in that it can handle alloys high or low in zinc and can change from one alloy to another. The furnace is not capable of a very high rate of production and is not so susceptible to close temperature control, nor does it mix the metal as well as some other types. These, with its rather poor performance as to power consumption on 10-hour operation, are its greatest disadvantages.

GENERAL ELECTRIC FURNACE.

A furnace similar to the Baily in that the bulk of the heat is reflected onto the hearth from the roof but differing in the way the heat is generated has been developed by the General Electric Co. This is described by Valentine⁵⁰ and by Collins.⁵¹ The principle of this furnace can be seen from figures 17, 18, 19, and Plate IX (page 125).

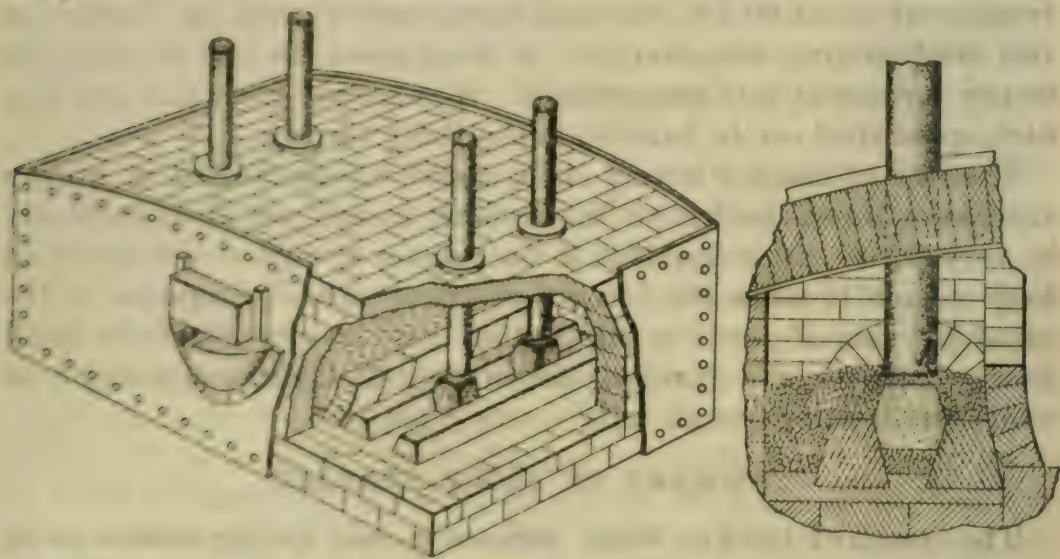


FIGURE 17.—Diagram of design of General Electric furnace, with detail of heating element.

A hearth is provided in the central part of a large furnace enclosure. Each side of the hearth, at each end of the furnace, is a bed of carbon slabs over which is piled granular resistor carbon. The granular material is held up by the carborundum end walls of the hearth. Two vertical electrodes (graphite, 5 or 6 inches in diameter) project through water-cooled rings in the roof at each end (four electrodes in all). The electrode holders are also water-cooled. The tips of

⁵⁰ Valentine, I. R. U. S. Patent 1,242,275, Oct. 9, 1917.

⁵¹ Collins, E. F. U. S. Patent 1,271,280, July 2, 1918; Electric furnace for melting carbonaceous materials and their alloys; Jour. Cleveland Eng. Soc., vol. 11, 1919, p. 293; Foundry, vol. 41, 1919, pp. 281-282; Metal Ind., vol. 17, 1919, p. 221; Chem. Met. Eng., vol. 21, 1919, p. 872; Also, Collins, Electric furnace replacing crucibles; Iron Age, vol. 184, 1919, p. 212; see also H. John, H. M., Discussion of above paper; Chem. and Met. Eng., vol. 21, 1920, p. 118.

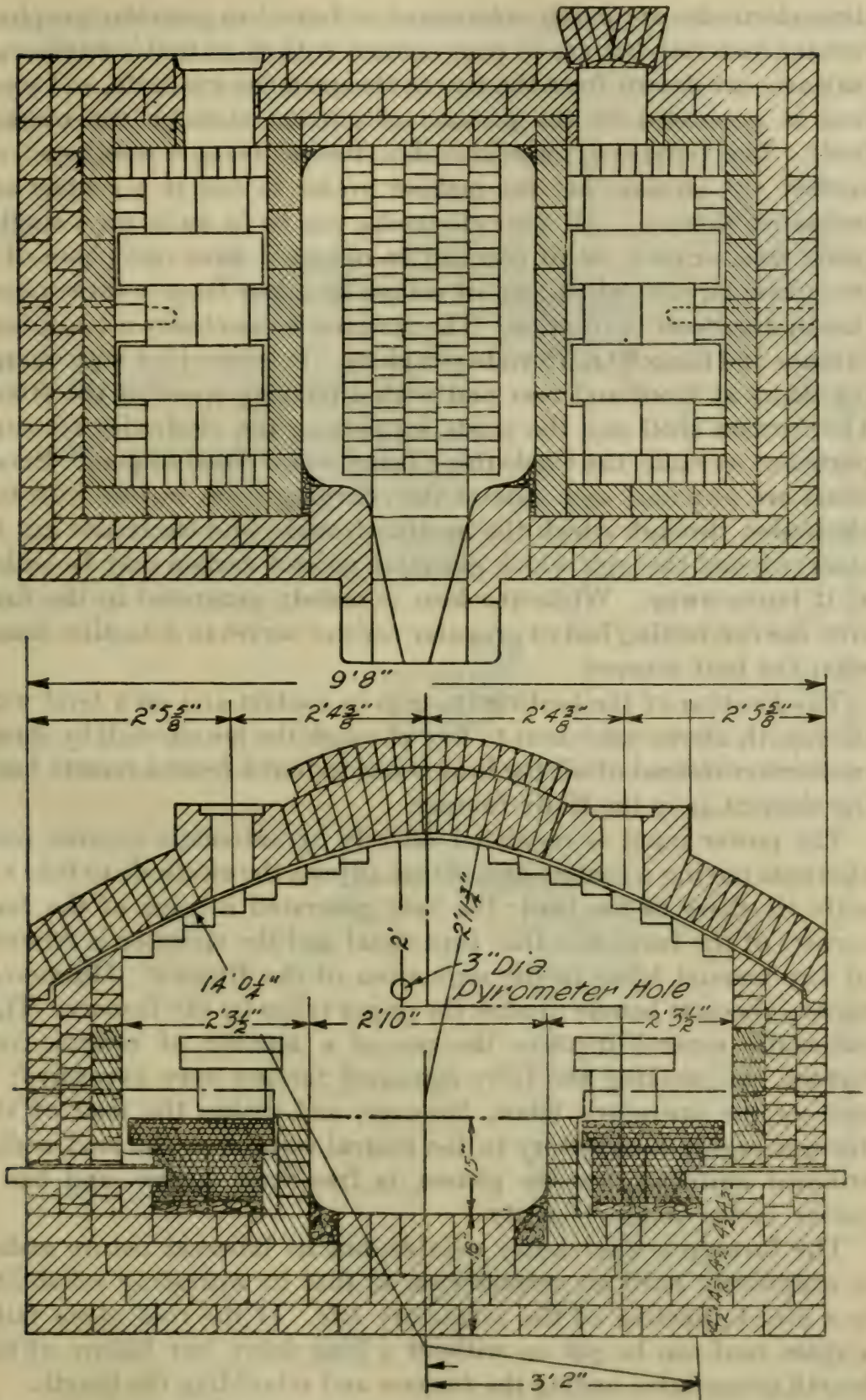


FIGURE 18.—Diagram of General Electric rectangular furnace.

these electrodes are partly submerged or buried in granular graphite resistor material, but are in poor contact with it, so that a number of tiny arcs are drawn from the tips to the granular graphite, and some heat is generated by the passage of current through the resistor itself. The furnace is sometimes described as being a smothered, or muffled arc furnace, but the makers prefer to call it a contact-arc resistance furnace. All four electrodes can be in series on a single-phase line, or each set of two can be operated from one phase of a two-phase circuit, which can of course be taken from a three-phase line by the Scott connection. The furnace is essentially a two-phase furnace and takes 60 to 70 volts per phase. It is provided with charging doors at front and rear and with a pouring spout at the front. The furnace shell and the masts supporting the electrodes are supported on a cradle, the whole thing being motor tilted to pour. Small doors are provided each side of the charging door, in line with the electrodes, through which the heating troughs and electrodes can be observed, and through which granular resistor carbon may be added as it burns away. While the heat is mainly generated in the four arcs, the conducting bed of granular resistor serves to delocalize somewhat the heat sources.

The location of the heating troughs in contact and on a level with the hearth allows some heat to flow through the hearth wall by direct conduction instead of all the heat being radiated from a remote heating element as in the Baily furnace.

The power input is regulated entirely by automatic control, each electrode having a control device that adjusts the electrode to take exactly its share of the load; the heat generated in each of the four corners of the furnace is thus kept equal and the operator is relieved of any manual labor in the regulation of the furnace. He merely turns a rheostat handle to alter the power taken by the furnace. This automatic control involves the use of a number of meters, contactors, etc., making the fully equipped furnace very expensive; it reduces the operator's labor, however, and makes the load of the furnace highly satisfactory to the central station, as the load is distributed uniformly on the phases, is free from surges, and has a power factor of nearly unity.

The furnace is electrically reliable, but its inherent nature makes it excessively hard on refractories, so that its operating reliability is a direct function of the refractory life. If the roof alone fails, a spare roof can be put on without a long delay, but failure of the hearth necessitates cooling the furnace and rebuilding the hearth.

The furnace in its usual size has a capacity of 1,500 to 2,500 pounds and is provided with a total transformer capacity of 400 kv. a., in the 14-ton size, about 300 to 325 kw. being used normally. This type allows a very much higher rate of power input than in the case

of the Baily furnace, which is rated at only 105 kw. for a capacity of 1,000 to 1,500 pounds.

The source of heat is more localized than in the Baily, and the temperature of this source is higher. Though the arcs are to some

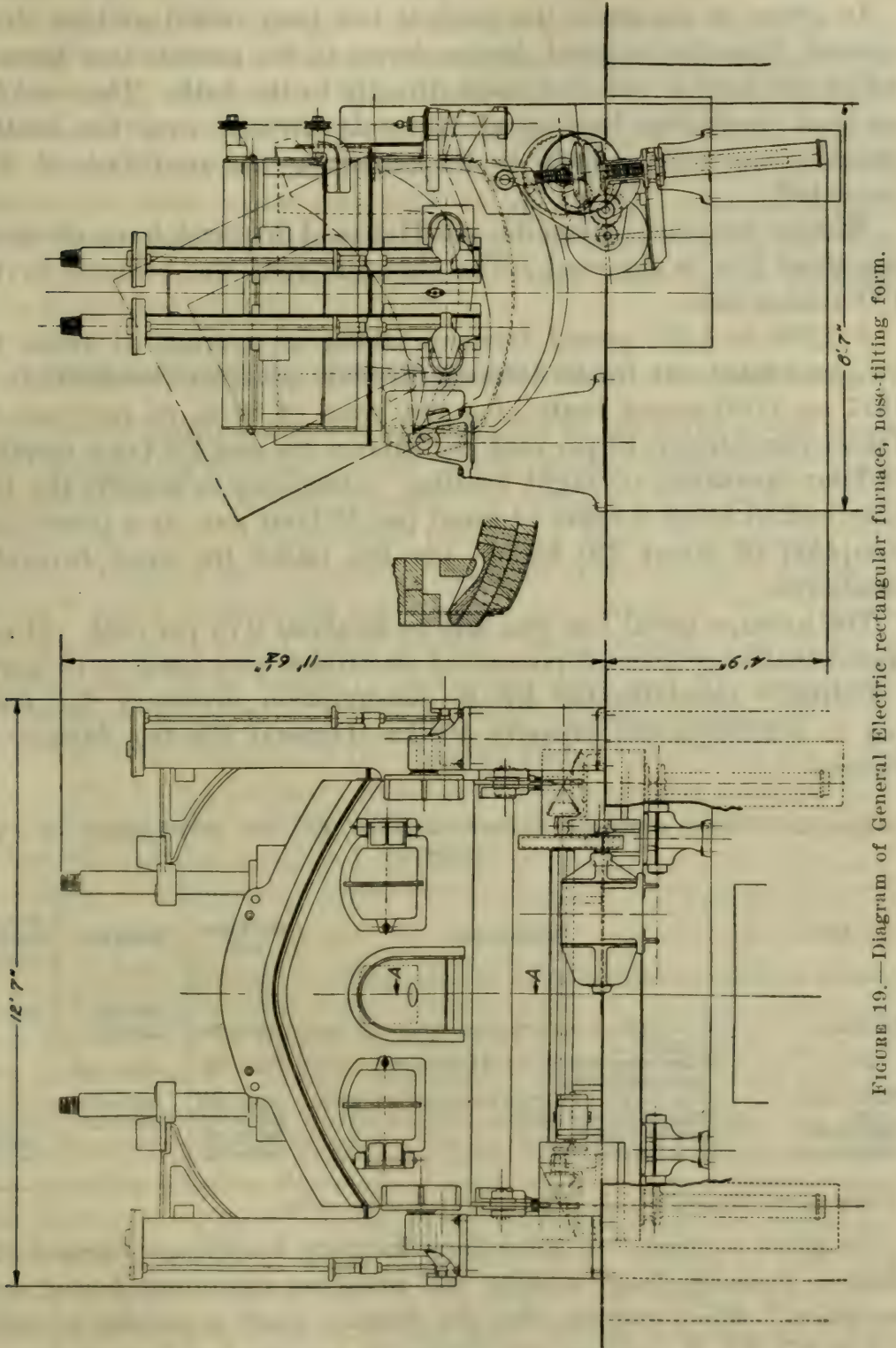


FIGURE 19.—Diagram of General Electric rectangular furnace, nose-tilting form.

degree smothered, the temperature around the tips of the electrodes is not far below that of the arc. The high temperature energy must

be reflected back mainly from the roof and end walls before it can reach the hearth. Almost no part of the heat goes to the bath by direct, unreflected radiation, as it does in the ordinary indirect-arc furnace.

In order to maintain the roof, it has been raised and its shape altered, from the original design shown in the patents to a form in which the heat is reflected more directly to the bath. The roof has no heat insulating lagging at the ends, directly over the heating troughs, and only a little in the center, as the roof fails if it is insulated.

Munroe fire brick, chromite, and Hybrand fire brick have all shown too short life in the roof. The chromite roof was reduced by the CO atmosphere.

A 1,000 to 1,500 pound furnace, taking an average of about 170 kw., was tried out in the General Electric plant at Schenectady in 1917 on 1,000-pound heats of a red brass of 80 to 85 per cent Cu (sheet punchings), 10 per cent Zn, balance Sn and Pb (new metals), 10-hour operation, no night heating. According to reports the furnace melted about 8 heats (4 tons) per 10-hour day, at a power consumption of about 350 kw. h. per ton under the most favorable conditions.

The average metal loss was said to be about 0.75 per cent. It was stated that only about 3 pounds of electrodes were used in 10 hours.

Collins⁵² tabulates the kw.-h. consumption necessary for melting in a 2,000-pound capacity 400-kw. General Electric furnace as follows:

TABLE 32.—*Claims made by General Electric Co. for performance of 1-ton furnace.*

Alloy.	Composition.	Kw. h. per ton.	Metal loss.	Pouring temperature.
			<i>Per cent.</i>	<i>Degrees.</i>
Red brass.....	80 Cu, 10 Zn, 6 Sn, 4 Pb, from scrap and new metal.	250 to 400	0.25 to 0.7	.....
Do.	Yellow scrap and Cu or red brass and Zn, with gates and chips.	225 to 300	.15 to .50	1,300
Yellow brass.....	60 Cu, 30 Zn, 4 Pb, from scrap and new metal.	220 to 350	.50 to 1.0	.....
Do.	Scrap, gates and chips.....	200 to 275	.40 to 1.0	1,100
Copper nickel.....	Scrap and billets.....	500 to 750	.....	a 1,600
Nickel silver.....	Scrap Cu, scrap Ni.....	500 to 750	.....	a 1,650

* These pouring temperatures appear abnormally high to the writer.

He gives a chart "to show how foundry handicaps prevent the electric furnaces from making red brass on minimum power consumption," which assumes that the furnace itself is capable of melting at 275 kw. h. per ton plus 25 kw. h. per ton lost in transformer

⁵² Collins, E. F., *Electric furnaces for melting nonferrous metals*; Foundry, vol. 47, 1919, p. 329; Jour. Cleveland Eng. Soc., vol. 11, 1919, p. 293.

and secondary leads; that is, 300 kw. h. is taken as the standard of what the furnace should do under perfect foundry conditions. The chart shows that the actual power used, with these handicaps, was about 350 kw. h. per ton.

No statement is made as to whether or not this chart includes pre-heating the furnace. Another chart shows that the furnace is pre-heated empty about three hours before charging, and the first heat was charged about half an hour before the foundry 10-hour working day begins, the production averaging $4\frac{1}{3}$ tons per day, or about 825 pounds per hour, under imperfect foundry conditions, although in the text the melting rate is once given as 1,500 pounds per hour, and again as 1,700 pounds per hour. These latter figures probably refer to 24-hour operation.

GENERAL ELECTRIC FURNACE AT PLANT OF CRANE CO.

A General Electric furnace was installed at the plant of the Crane Co., Chicago, for commercial test by the General Electric Co., a representative of the General Electric Co. being present whenever the furnace was run. Intermittent tests were made throughout 1918, continual running being impossible because of the repeated failure of the roof which necessitated replacement and redesign. The furnace was run on valve metal, ladle poured. Much trouble was found in making cored valve bodies to stand hydraulic test, the percentage of "leakers" being far above that from crucibles, according to the Crane Co., but according to the General Electric Co., when the metal was poured with a properly preheated ladle, defective castings from the electric and the crucible furnaces ran neck and neck. One source of trouble was the structural weakness of the hearth, the carborundum walls of which were under the pressure of the molten metal on one side and served to retain the hot resistor on the other. Metal seemed to leak through a crack in the hearth and to collect silicon that had been produced either by reduction of silicates in the ash from the resistor, or by the decomposition of carborundum at a hot spot in the resistor. At any rate, silicon was picked up, the product from the furnace being often ruined by silicon, although the same charge melted in crucibles did not pick up silicon. There was also some question whether this class of work could be satisfactorily made with ladle-poured metal, owing to the fact that there was more oxidation of the stream of metal in pouring from furnace to ladle and then from ladle to mold than in the single pour from a crucible.

At any rate, this furnace, as operated, did not impress the Crane Co. by quality of product. No difference was seen in metal losses

between this electric furnace and crucibles. The average power consumption per ton was excessively high during the periods of roof troubles, but came down under the most favorable conditions to about 400 kw. h. per ton for 10-hour operation.

The furnace was finally dismantled and returned to the makers in 1919. Detailed data on the experience with this furnace at the Crane Co. would be very instructive, as they might indicate whether the inapplicability of the furnace to the type of work was due to the furnace, to its method of operation, or whether no electric furnace would handle that work. By the terms of the contract under which the General Electric Co. had supplied this furnace for test, the Crane Co. was not able to give out detailed data.

The rejection of the furnace does not seem to be due to any prejudice of the Crane Co. against electric furnaces, as the firm is well satisfied with its Heroult steel furnace and is at present trying other types of electric brass furnaces.

Two other General Electric furnaces are installed at the McNab & Harlan Manufacturing Co. To an inquiry addressed to this company reply was made that the furnace had never been used for melting brass, but only for a higher melting, patented alloy, "Aterite," and that the company would object to furnishing any data or information, as the alloy is made under a formula which they do not disclose.

It is reported from other sources⁵³ that the alloy is a nickel alloy somewhat similar to an 18 to 30 per cent zinc-nickel brass (German silver), but low in nickel and carrying iron and lead.

Metal losses as low as 1 per cent and power figures as low as 400 kw. h. per ton on 16-hour operation have been claimed operating on alloys of this type poured at about 1,400° C. (2,550° F.) and perhaps even up to 1,600° C. (2,900° F.).

It is a pity that full details on the lining used and its life can not be obtained, for if the furnace shows reasonable reliability as to linings on such service it ought to be almost free from lining troubles on brass or copper.

GENERAL ELECTRIC FURNACE AT UNITED STATES COPPER PRODUCTS CORPORATION.

Another of these furnaces is installed at the plant of the United States Copper Products Corp. This is a 1½-ton furnace, run 24 hours a day at 300 to 325 kw., melting copper, which is

⁵³ Compare Collins, E. L. Melting nonferrous metals and their alloys in the electric furnace. *Ann. Cleveland Eng. Soc.*, vol. 11, 1919, discussion, p. 316; Vickers, C., What is Aterite? *Foundry*, vol. 48, 1920, p. 79; Merica, P. D., Miscellaneous alloys of nickel: *Foundry and Met. Eng.*, vol. 24, 1921, p. 652.

poured at 1,200° to 1,230° C. (2,200° to 2,250° F.). Twelve heats per day are obtained. The power is on about 1½ hours per heat, and it takes three-fourths of an hour to charge and pour. In average operation it is reported that it takes 550 kw. h. per ton of copper on 24-hour operation, though if more rapid charging and pouring were done this figure might perhaps be reduced to 300. There is no weighable loss in melting copper. On the basis of about 25 heats made with this furnace on 60:40 brass, it was thought that by hurrying the charging and pouring to cut the time the power is off to 15 minutes, eighteen 1-ton heats could be made in 24 hours.

If power were on 19 hours out of the 24, and the furnace run at 300-kw. average, the power consumption would then figure out to 310 kw. h. per ton. The metal loss on heavy yellow scrap is about 1 per cent. The representative of the General Electric Co. stationed at this plant stated the furnace did not work well on fine yellow scrap or turnings.

With a Hybrand brick roof the furnace, melting copper, gave from 125 to 180 heats. At 12 heats per day, this means putting on a new roof every 10 to 15 days. In the General Electric plant at Schenectady the longest roof life in melting brass so far reported was 350 heats. The use of corundite is expected by the makers to double this life.

Not only has the roof given much trouble on the furnace at the United States Copper Products Corp. but the carborundum hearth has failed, letting metal run into the resistor on several occasions. The design of later furnaces has been slightly altered, lowering the hearth and arranging it so that metal is less likely to work through into the resistor.

A spare roof must be kept ready to put on, just as is done with steel furnaces, because of the danger of the roof failing at any time. The furnace is purposely constructed both as to walls and roof with so little lagging to prevent the refractories getting too hot on the inside of the furnace that, in contrast to most electric brass furnaces, it is uncomfortably warm in the vicinity of the furnace, though not so hot as it would be near a one-ton fuel-fired furnace. The Washington Navy Yard, Washington, D. C., and the Ohio Brass Co., Mansfield, Ohio, have installed 1½-ton General Electric furnaces.

The smothered arcs of the General Electric furnace are very similar to a plan suggested by Rennerfelt.⁵⁴

Rennerfelt also suggests a design, evidently intended primarily for melting glass, of a furnace very similar in principle to the Gen-

⁵⁴ Rennerfelt, L., U. S. Patents 1,305,167, May 27, 1919, and 1,313,834, Aug. 19, 1919,

eral Electric furnace in which, as shown in figure 20, three smothered arcs, one for each phase of a three-phase circuit are arranged about the furnace wall, the central part of the furnace containing either a melting hearth or crucibles. Rennerfelt emphasizes the severe treat-

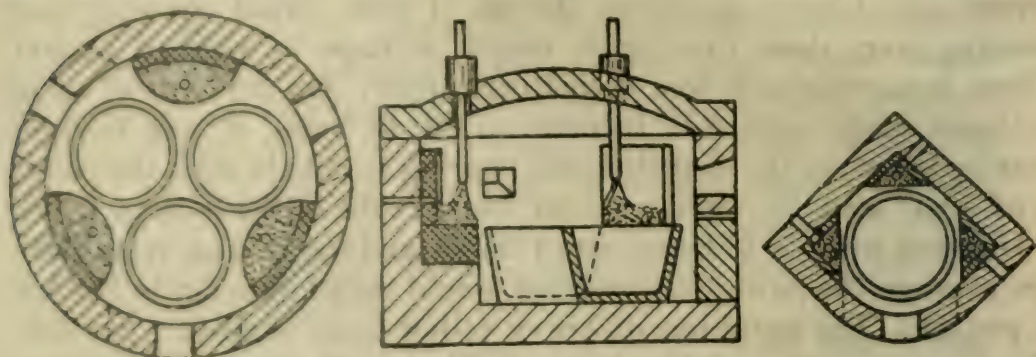


FIGURE 20.—Rennerfelt circular furnace design.

ment such an arrangement imposes on the refractories near the smothered arcs and reiterates the necessity of using extremely refractory materials at such points on this account. The General Electric Co. has recently developed a modification of its brass fur-

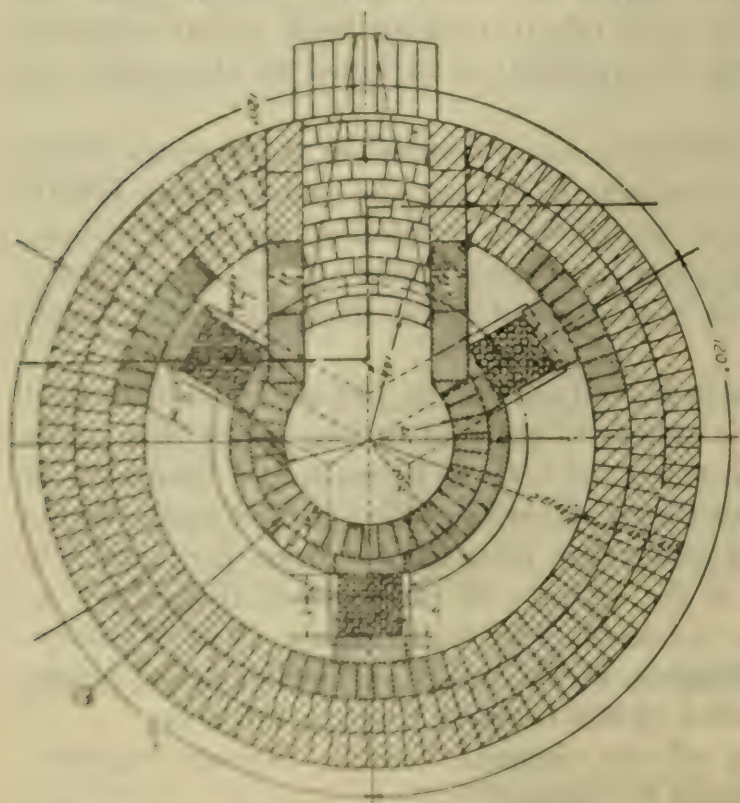
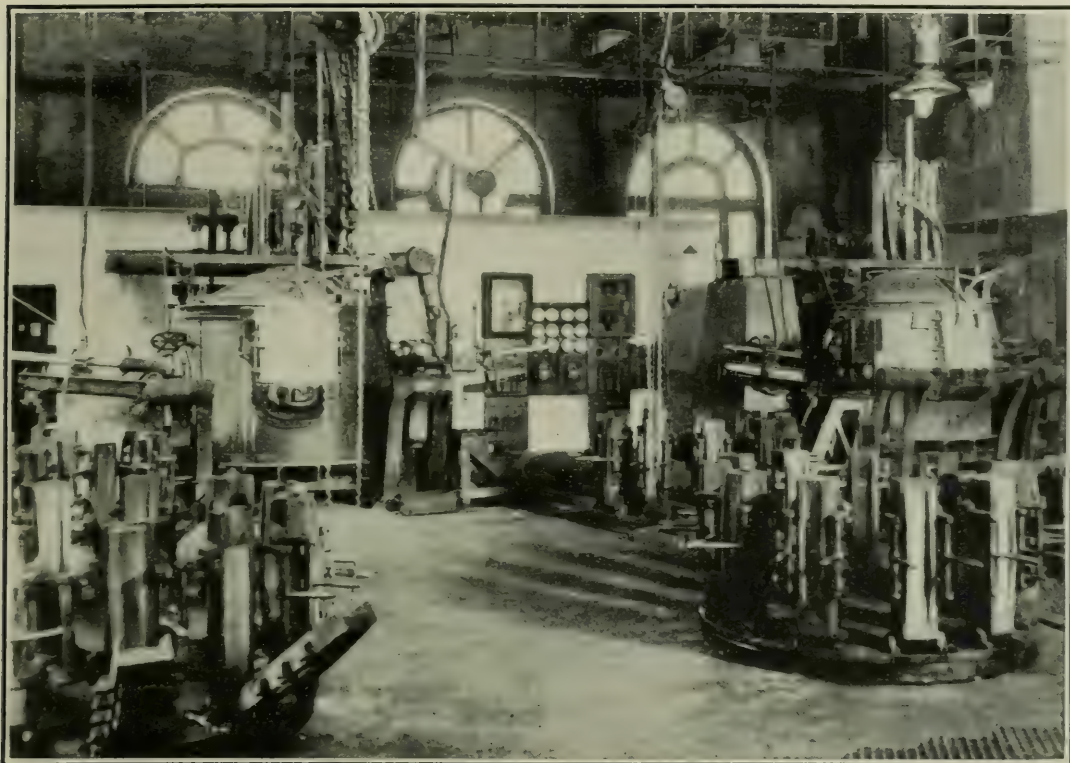


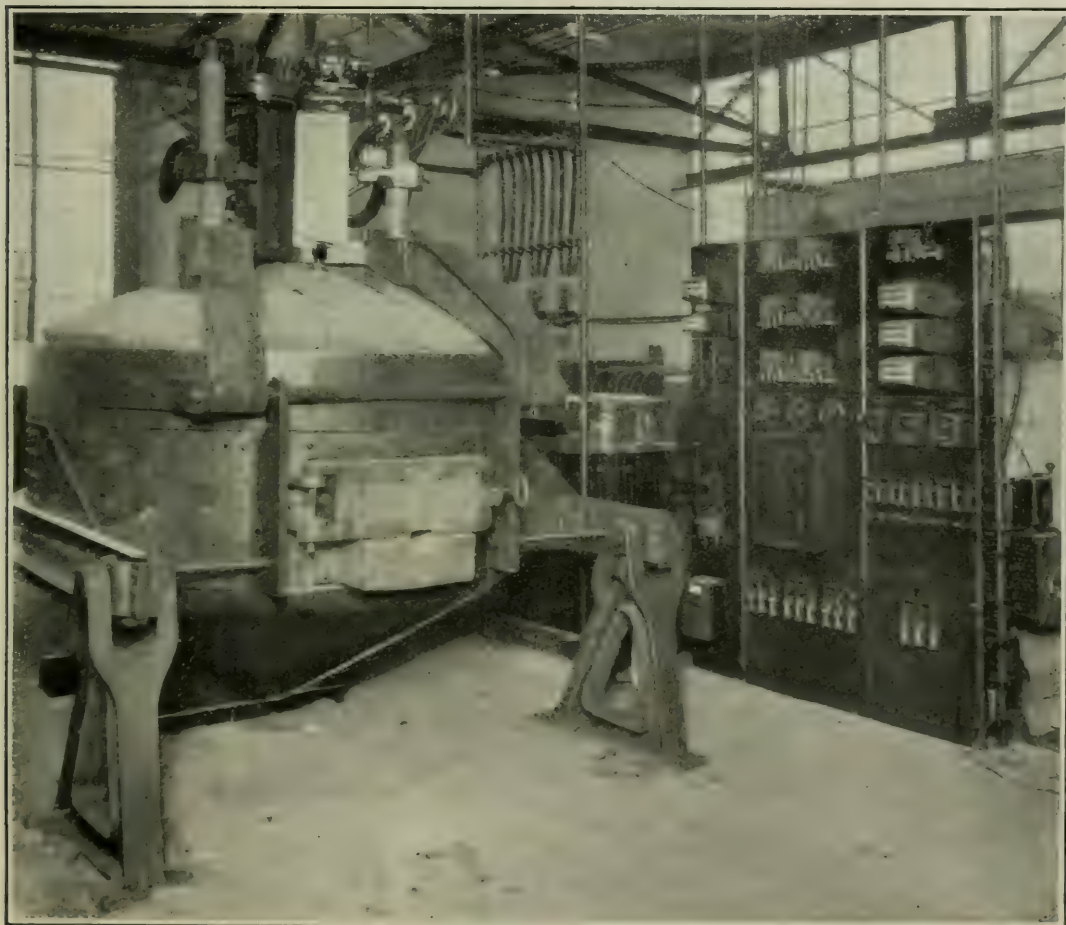
FIGURE 21.—Plan of General Electric circular furnace.

graphite over carbon wearing blocks, which are electrically connected.

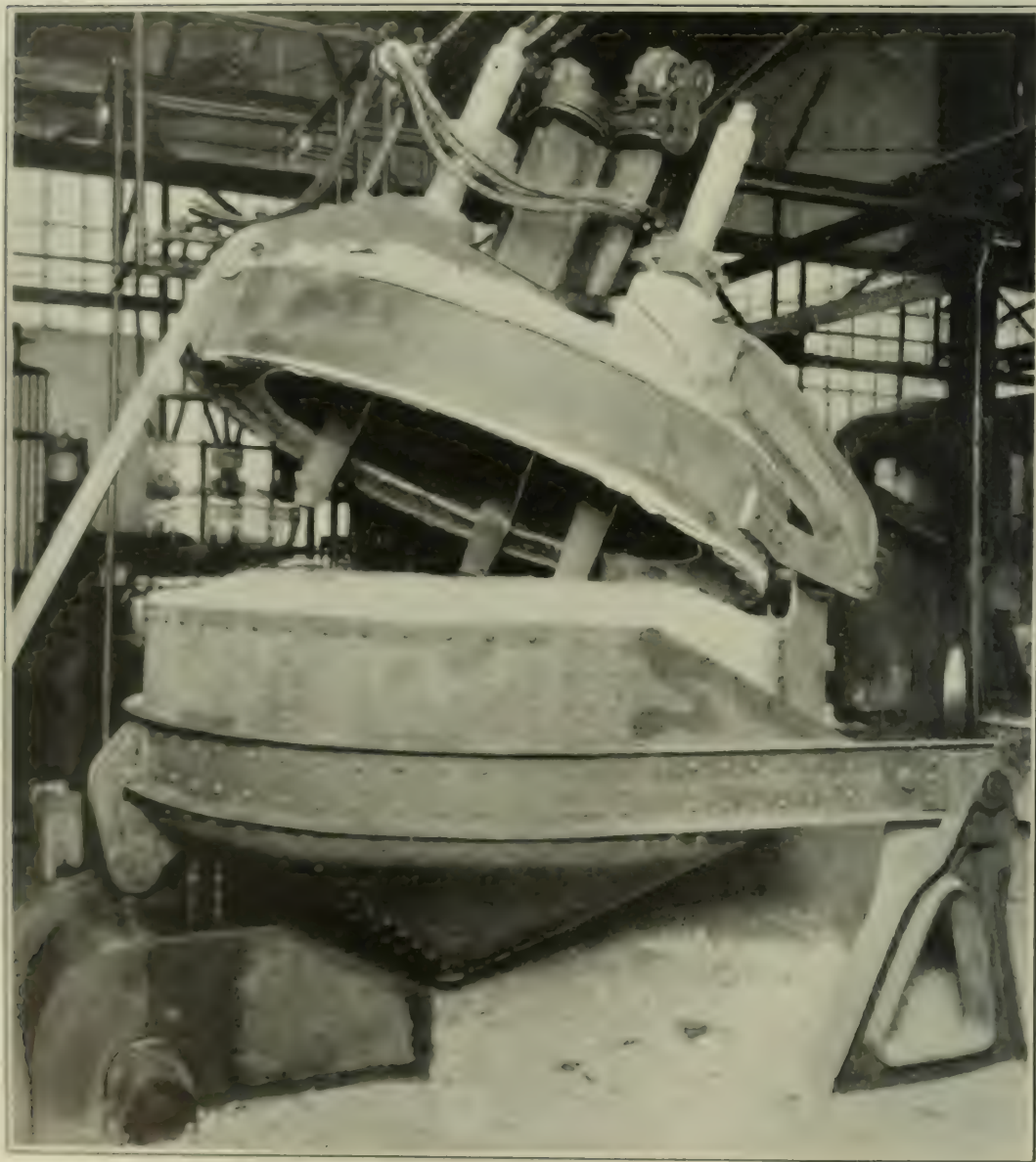
nace, which, as is shown in figure 21, Plates X, B, and XI, is similar to the Rennerfelt scheme. The Rennerfelt plan uses open arcs to a bed of granular material, while the General Electric tries to avoid open arcs. In the new General Electric furnace, first tried in an 800-pound size and later developed in a 1,500-pound and larger sizes, there are three electrodes extending downward through the roof to three beds of granular



A. TWO NOSE-TILTING RENNERFELT FURNACES AT THE PHILADELPHIA MINT.



B. FRONT VIEW OF 1,500-POUND, 250-KW. HEARTH CAPACITY, GENERAL ELECTRIC NONFERROUS ELECTRIC FURNACE ARRANGED FOR NOSE TILTING; MELTING POSITION.



FURNACE SHOWN IN PLATE X, B, WITH ROOF LIFTED.

The furnace is circular in form, and the general arrangement of hearth and heat source is quite similar to that in the Baily furnace. Figures obtained in the General Electric Co.'s works⁵⁵ on the new type indicate that the 1,500-pound 250-kw. size will melt yellow brass at 250 to 300 kw. h. per ton, 24-hour operation, and on 9-hour operation at 325 to 375 kw. h. per ton. Metal loss on an alloy with 30 per cent zinc was 1.14 per cent on one set of heats. Electrode consumption is given as $1\frac{1}{2}$ to $2\frac{1}{2}$ pounds of graphite per ton, and about 1 pound of granular graphite per ton is required also. The life of the lining is stated to have been remarkably good on the experimental furnaces.

The prices of the General Electric furnaces, complete with transformers, meters, automatic electrode control, switchboard, etc., were, in April, 1920, as follows:

TABLE 33.—*Claims of makers of General Electric furnaces for melting brass, April, 1920.*

Capacity.	Kw.	Price.	Kw. h. per ton on brass heated to 1,100° C. 24-hour continuous operation.	Production, per hour on 24-hour operation.
<i>Pounds.</i> 3,000 2,000	400 250	\$17,000 16,000	250 275	<i>Pounds.</i> 2,250 1,500

The General Electric furnaces of the older type are said to have operated two years at Schenectady on the same linings, melting aluminum.

The same sizes as are used on brass are used for aluminum, but the transformer capacity supplied is lower.

SUMMARY ON GENERAL ELECTRIC FURNACE.

The General Electric furnace has very good electrical characteristics and can be operated at a low labor cost. It is capable of a good rate of production. The metal losses appear low, though few data on alloys high in zinc are available.

The design of the furnace is thermally inefficient, the transfer of heat from its source to the metal is very indirect, and there is a good deal of waste space in the furnace, yet this is somewhat compensated for by the high rate of power input.

The weak point of the furnace is the life of the refractories. The furnace has evidently been designed with the object of making a load desirable to the central station. That object has been fully

⁵⁵ See Winne, H. A., Recent developments in electric furnaces of the muffled-arc type: *Trans. Am. Electrochem. Soc.*, vol. 41. (In press.)

reached, but further commercial experience must be obtained with it before its relative value to the foundry itself, as compared with other commercial furnaces, is thoroughly understood.

Eastick⁵⁶ has criticized the design of the General Electric furnace.

RENNERFELT OR HAMILTON AND HANSELL REVERBERATORY FURNACE.

A more recent use of the smothered arc as a heat source is in the Rennerfelt reverberatory type.⁵⁷

This type, shown in figure 22, would usually be made tilting in smaller sizes, and tapping in the larger; vertical electrodes, usually

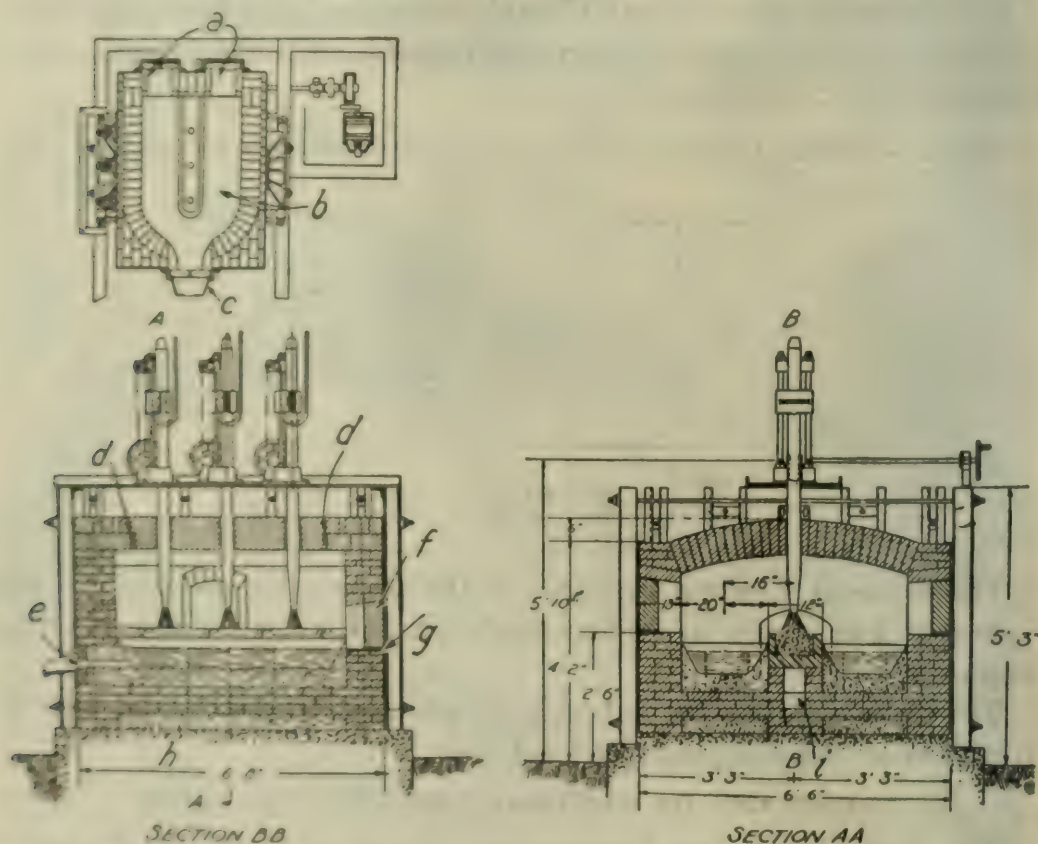


FIGURE 22.—Diagram of Rennerfelt reverberatory-type furnace: *a*, charging door; *b*, melting chamber; *c*, spout; *d*, wooden strips to allow for expansion; *e*, tap hole; *f*, skim door; *g*, skim plate; *h*, sand tightly packed; *i*, air duct.

three, draw arcs to a heating trough of carborundum, containing granular carbon or graphite. The voltage used is 100. The trough runs through the center of the furnace, with hearths for metal on each side. This design, using arcs, avoids the limitation on power input which makes the Baily inefficient as to power consumption. It should be more efficient than either of the General Electric types, as the heat is generated in the middle of the furnace and not near the end walls, so that it does not have to travel so devious a path before

⁵⁶Eastick, Y. H. A. Letter to editor, *Metal Industry*, vol. 19, 1921, p. 241.

⁵⁷Rennerfelt, I., U. S. Patent 1,312,524, Aug. 19, 1919; DeFries, H. A., Rennerfelt electric reverberatory furnace, *Chem. and Met. Eng.*, vol. 22, 1920, p. 280.

it reaches the metal. As the electrodes enter at the center of the arch instead of at the ends, and the roof and side walls are both farther from the source of heat, the refractory life should be much increased over that in the General Electric furnaces.

The two hearths might be separate, and handle two different alloys at the same time, so that the furnace could operate on separate 1,000-pound charges with the efficiency of a 1-ton furnace. All the advantages of polyphase power and of automatic control shown by the General Electric furnace would be present in this.

In the opinion of the writers the location of the heating trough, embedded between the two hearths and below the metal level, is a source of weakness, as analogous construction in the General Electric furnace caused trouble from metal working its way into the trough. There also seems to be danger of leakage into the air duct provided below the trough to cool it. The reliability of the furnace might be largely increased if the air duct were replaced by a solid carborundum brick wall between the two hearths, thus making the construction of the whole hearth solid, and if carborundum bricks were placed at intervals across the carborundum wall above the metal level to support the trough, leaving spaces for ventilation and radiation from the bottom of the resistor. When the trough of the present design needs repair, both hearths will have to be partly torn out and rebuilt; the proposed design would allow replacing the trough, which is doubtless the weakest point, without interfering with the hearths.

Some alteration of this nature was, in fact, found necessary when the furnace was put to an actual test, since the makers report that in a trial of a 75-kw., 300-pound furnace at the Chicago Faucet Co., early in 1921, it was found desirable to raise the carborundum trough, which is now entirely exposed. On brass containing 60 per cent Cu and 40 per cent Zn the furnace, when fully hot (as in 24-hour operation) has melted at the rate of 330 kw. h. per ton, which is a good performance for so small a furnace. The metal loss is about 1 per cent on heavy scrap and 2 per cent on borings. The electrode consumption varied between 3 and 4 pounds per ton, and that of granular carbon in the resistor trough was about 2 pounds per ton. In one day's run 6 heats of 300 pounds each were made, the furnace being preheated for an hour in the morning. The first heat required one and one-half hours, later heats not over one hour each. The makers claim 360 to 480 kw. h. per ton on red brass, 8-hour operation. The net loss is said to be one-half of 1 per cent on red brass.

ARC FURNACES.

Direct-arc furnaces in which the arc plays directly on the charge have found but little use on copper alloys because of the intense local heat of the arc, which supplies heat more rapidly to the surface

of the charge than it can be carried through the body of the charge by conduction. This results in local overheating and in consequent loss of volatile constituents.

Over 30 years ago Slawianoff⁵⁸ described an apparatus for melting metal by the arc for such purposes as filling up blowholes in castings. He says: "Experiments show that brass, after electrical casting, becomes materially altered chemically in consequence of the burning out of the zinc."

HEROULT-TYPE FURNACE.

Hansen⁵⁹ made an experimental heat of 5,000 pounds of copper in a Heroult-type steel furnace, using a slag 1 to 1½ inches deep. Although the average temperature of the metal was not over 1,300° C., copper was either volatilized as a gas or tiny particles of metallic copper mechanically ejected, and the workmen were made ill. There were two cases of copper poisoning at the Titanium Alloy Manufacturing Co. when making titanium copper in a direct-arc furnace, two men being nearly killed before proper ventilation was secured. There is evidently a real danger in operating a direct-arc furnace on copper, at least under some conditions. In any experimental work on the direct-arc melting of copper good ventilation should be provided and the workmen supplied with suitable respirators or masks, at least until it is proven that no dangerous fume will be given off under the conditions of operation.

To avoid the volatilization of copper from a direct-arc furnace it would probably be necessary to hold the power input down to a rather low rate, so as to allow time for the heat to become more uniformly distributed through the melt. Perhaps some method of moving the furnace to stir the charge would work in this case, provided the stirring did not alter the distance from electrode to bath sufficiently to cause the arc to break.

There seems to have been no trouble due to copper fume, in the operation of direct-arc furnaces on Monel metal or bronze.

A three phase 1,500-pound furnace of this type was used in 1915 and 1916, but probably not thereafter⁶⁰ at the plant of the Canadian Brakeshoe Co. Red brass was melted under a slag of molten glass. The metal loss was stated to be under 2 per cent. The furnace was not used on material of high zinc content.

⁵⁸ Slawianoff, N., English Patent 16,279, of Oct. 13, 1890; U. S. Patent 577,329, Feb. 14, 1907; application filed Jan. 29, 1891.

⁵⁹ Hansen, C. A. Copper poisoning; *Met. and Chem. Eng.*, vol. 9, 1911, p. 67; *Electric melting of copper and brass* *Trans. Am. Inst. Metals*, vol. 6, 1912, p. 110.

⁶⁰ Dary, J. E., Jr., private communications.

The Driver-Harris Co., Harrison, N. J.,⁶¹ operate two basic lined Heroult direct-arc furnaces, rated at 600 kw. and 2 tons capacity, but up to 3 tons are now charged. Three heats are made each day of 12 to 14 hours per furnace. Among the various alloys made are a 30 per cent nickel steel and one with 85 per cent nickel and 15 per cent chromium. The furnaces are therefore to be included both among those melting ferrous and those melting nonferrous alloys.

The power consumption averages 650 to 750 kw. h. per ton, and the consumption of carbon electrodes is 14 pounds per ton. The roofs last only about 25 heats. The gross metal loss is given as about 2½ per cent.

Another Heroult furnace, at the plant of the Hiram Walker & Sons Metal Products Co., Ltd., in Walkerville, Ontario, is melting nickel-iron-chromium alloys.

Direct-arc furnaces of the Snyder, Heroult, and Greaves-Etchells types are in use⁶² for melting such alloys as nickel-chromium, Monel metal, and cupronickel.

SNYDER TYPE FURNACES.

Haynes⁶³ stated in 1917 that though three electric furnaces of the Snyder type had been used in melting Stellite, a cobalt-chromium alloy, poor results had been traced back to the electric furnace, and the electric furnace had been discarded in favor of melting in covered crucibles. Mr. Haynes was careful to say that he did not mean to assert it would be impossible to use the electric furnace successfully, and that investigations were planned to try it out further.

In February, 1920, Mr. Haynes⁶⁴ said that the troubles had been overcome, and the furnaces were now giving highly satisfactory service. The power consumption, under normal conditions, runs from 800 to 1,200 kw. h. per ton. In work on Stellite the Haynes Stellite Co. has been able to get as much as 3,000 heats from a lining, an astonishing figure.

A 60-kw., 200 to 300 pound Snyder furnace has also been in use on a cobalt-chromium alloy at the Chrobotic Tool Co.,⁶⁵ Chicago, Ill., which is said to get out about one heat per hour when the fur-

⁶¹ Compare Easton, W. H., *Electric furnace for melting alloys*: Elec. World, vol. 72, 1918, p. 295; see also Major, R. M., *Electrical production of alloys*: Trans. Am. Electrochem. Soc., vol. 37, 1920, p. 441.

⁶² Compare editorial, *Met. Ind.* (London), vol. 14, 1919, p. 111; Etchells, H., *Met. Ind.* (London), vol. 14, 1919, p. 113; Easton, W. H., *Electric furnaces for melting alloys*: Elec. World, vol. 72, 1918, p. 295; Diller, H. E., *Foundry standardizes nickel alloy*: Foundry, vol. 48, 1920, p. 209; Arnott, J., *Monel metal*: *Metal Ind.* (London), vol. 16, 1920, p. 327; Brooks, G. D., *Discussion*, *Metal Ind.* (London), vol. 16, 1920, p. 346.

⁶³ Haynes, E., *Discussion*, *Jour. Am. Inst. Metals*, vol. 11, 1917, p. 433.

⁶⁴ Haynes, E., private communications; see also Haynes, E., *Stellite*: Trans. Am. Electrochem. Soc., vol. 37, 1920, p. 380.

⁶⁵ See anonymous, *Chrobotic cast milling cutters*: *Machinery*, vol. 26, 1919, p. 354.

nace is fully hot; this figure corresponds to about 600 kw. h. per ton on continuous operation. The roofs of these small furnaces are said by the makers to stand up to 400 heats.

It has been stated⁶⁶ that the Green direct-arc furnace would melt brass, but no data are given.

In 1912 the Metallurgic Engineering Co. advertised the Snyder furnace for melting brass, stating: "If you are making copper castings for conductivity purposes, the conductivity of electric furnace castings is much higher; if you are making brass, the loss in zinc is much lower. For steam and hydraulic fitting, the electrically melted copper and bronzes are more dense and will not seep under high pressure and superheat." On attempting to get full data from the advertisers it was stated that a 1½-ton, 300-kw. steel furnace was used, a charge of 1,200 pounds copper, 600 pounds zinc, 60 pounds lead, and 200 pounds brass scrap, or 2,060 pounds total, being melted in one hour, using 198 kw. h., the furnace being at steel-melting temperature at the start, and hence having a good deal of stored heat. A thin glass slag was used. No figures could be obtained on metal losses, the data as to the weight of metal poured being refused, but the statement was made that the loss was between ½ and 1 per cent. A representative of the Commonwealth Edison Co. who had witnessed the test said that dense clouds of zinc fume were evolved and the loss appeared to be high, but that owing to the presence of some molten steel in the furnace at the start the brass poured was contaminated with steel. The test was worthless for determining metal losses or power consumption, though it was apparently the basis for the advertisement. The firm later stated that the advertisement was premature and a mistake.

GREAVES-ETCHELLS FURNACE.

A Greaves-Etchells direct-arc furnace, 1,000 pounds, 300 kw., is in use at the Hoskins Manufacturing Co., Detroit, for nickel-chromium alloys.

Another Greaves-Etchells furnace has been sold to the Japanese mint for melting coinage bronze and silver, and still another has been sold to Lacheze et Fils, Dijon, France, for nonferrous alloys.

GRONWALL-DIXON FURNACE.

A Gronwall-Dixon furnace of 500-pounds capacity at the Cleveland Brass Manufacturing Co., Cleveland, Ohio, is melting "Clebrum," an alloy that has among its constituents chromium and, it is said, about 40 per cent of iron. The furnace might, therefore, be classed either among nonferrous melting furnaces or among furnaces for special steels, according to the classification of the alloy.

⁶⁶Engineering Record, Green direct-arc furnace, Iron Age, vol. 193, 1919, p. 1005.

SNYDER FURNACE OPERATING ON MONEL METAL.

A 1,000-pound, 150-kw. Snyder furnace is running on Monel metal at the Monel Metal Products Corporation, Bayonne, N. J.; its output approximates 5,000 pounds in 10 hours, and its power consumption about 600 to 850 kw. h. per ton. A slag about $\frac{1}{2}$ inch thick is used. The total loss of metal in the foundry is given as about 2 to $2\frac{1}{2}$ per cent, but exact figures for the melting loss are not available. The furnace roof, of high-grade fire brick, lasts 50 heats on the average, and has lasted for 90 heats. The hearth is made of ganister and does not have much longer life than the roof.

The furnace is said to be easier to operate and to give metal of better quality than that from an oil-fired reverberatory with pantype burner. Great care is taken to operate with the furnace tightly closed to avoid oxidation. It is stated⁶⁷ that a Moore direct-arc furnace, made by the Pittsburgh Electric Furnace Co., has been ordered for the Huntington, W. Va., plant of the International Metal Co., to melt Monel metal.

LABORATORY TEST OF DIRECT-ARC FURNACE MELTING YELLOW BRASS.

In April, 1915, the Bureau of Mines built a direct-arc furnace in order to determine the metal loss in melting yellow brass. Instead of a tilting-type furnace, one was built in which an ordinary No. 30-graphite fire-clay crucible, with a double handful of chip graphite in the bottom to protect the crucible from the arc when starting, was set on an electrode built into the furnace bottom. The upper, movable electrode, from which the arc was struck to the charge, was a 2-inch diameter graphite rod. The crucible was set into a fire-brick inclosure, only enough space being allowed between crucible and walls to admit the tongs for lifting the crucible. A tight cover (fire-brick slab) with a 2-inch diameter hole was put over the furnace after the crucible was in place, the upper electrode passing through the hole. In order to avoid loss by spattering, the crucible was not filled to its full capacity of 90 pounds, only 50-pound charges being used. The furnace ran at about 50 volts, 400 to 500 amperes.

Two alloys were melted, both in ingot form, no new metal being used, one of 80 per cent copper, 15 per cent zinc, $2\frac{1}{2}$ per cent tin, $2\frac{1}{2}$ per cent lead, the other of 67 per cent copper, 33 per cent zinc. A couple of pounds of green bottle glass was used as slag on the former, and about 3 pounds of salt on the latter. The results are tabulated below.

⁶⁷ Editorial, *The Foundry*, vol. 49, 1921, p. 583.

TABLE 34.—*Bureau of Mines test of small direct-arc furnace melting alloys high in zinc.*

Heat No.	Time.	Condition of furnace at start.	Zinc in alloy melted.	Weight of metal charged.	Weight of ingot poured.	Weight recovered from spillings and from slag.	Total weight recovered.	Loss.	Pouring temperature.	Kw. h. used.
	H. m.		Per cent.	Pounds.	Pounds.	Pounds.	Pounds.	Lbs. P. ct.	° C.	
1....	1 10	Cold....	15	50.00	45.80	0.30	46.10	3.90 7.8	1,150	24½
2....	1 0	Slightly warm.	33	51.25	45.65	1.20	46.85	4.40 8.6	1,070	19
3....	1 5	Cold....	33	52.35	47.25	1.05	48.30	4.05 7.7	1,050	20½
4....	1 0	Hot....	15	53.35	50.60	.30	50.90	2.45 4.6	1,140	19

Neither alloy was heated as hot as it would normally be heated in commercial practice. As soon as the alloy had started to melt down great clouds of zinc vapor came out about the clearance around the electrode, this being the only opening of the furnace that was not luted tight while running. The furnace was set up outdoors. Had it been inside it would have been impossible to have completed the runs on account of the fume. As losses of $4\frac{1}{2}$ per cent on a 15 per cent zinc alloy and $7\frac{1}{2}$ per cent on a 33 per cent zinc alloy, melting ingots, are decidedly higher than would be obtained in fuel-fired furnaces, it was evident that the direct-arc furnace was not fitted for use on alloys high in zinc.

TESTS OF SMALL SNYDER FURNACE.

In January and February, 1916, a 600-pound tilting Snyder⁶³ furnace was tested at the plant of the Chicago Bearing Metal Co., through whose courtesy a representative of the Bureau of Mines was present during part of the test.

The furnace was single-phase, rated at 100 kw. It had a rammed-in magnesite hearth, bonded with linseed oil, outside of which and next to the shell was a layer of rammed-in No. 26 J. M. asbestos cement. The roof was of silica brick. The lower electrode was a 1-inch diameter copper rod, water cooled outside the furnace and extending up through the refractory bottom to the hearth. The upper electrode was of 3-inch diameter graphite, coming down vertically through the dome of the roof. The roof, electrode and all, was raised and at the same time tilted back, by a handwheel, so that the furnace could be charged from the top. A sand seal between roof and furnace body made a tight joint. A pouring spout, closed with a fire-brick plug and fire-clay luting, was provided, through which, when the whole furnace, including the electrode support, was tilted by a second handwheel, the metal could be poured. Some 20 or 25

⁶³See Snyder, P. T., U. S. Patents 1,100,995, June 23, 1914; 1,167,026, Jan. 4, 1916; 1,223,229, Dec. 23, 1919; and 1,327,174, Jan. 6, 1920.

pounds of metal was usually retained in the bottom of the furnace between heats. The power supply was 60-cycle, 4,400 volts, which was stepped down to 440 volts and then by a second transformer containing a good deal of reactance to a lower voltage, probably around 110 to 125. A portable ammeter, voltmeter, wattmeter, and watt-hour meter were used on the 440-volt side of the second transformer for test purposes, the only meter provided with the furnace being an inaccurate wattmeter. The readings for the test were made by the testing department of the Commonwealth Edison Co.

The alloy melted, except in a few runs on a yellow brass made at the bureau's request, contained 70 to 75 per cent copper, 15 to 20 per cent lead, and about 6 per cent tin, the balance being impurities (zinc, lead, iron, etc.). Charges were made up of about half cupola ingot or heavy scrap railroad bearings and about half heavy borings free from oil or gates. The charge was quite free from nonmetallic material, not over 0.50 per cent being present at most. Metal losses were obtained by weighing the ladles before and after pouring. Ladle skimmings and metal spilled in pouring were not weighed but charged back with the next heat. Slag scraped from the furnace was kept separate and its recoverable nonmetallic content calculated.

The power input to the furnace averaged about 70 kw. and was never over 90 kw.

RUNS ON YELLOW INGOT.

Three heats were made on a yellow brass ingot of 67.8 per cent copper, 27.5 per cent zinc, 2.9 per cent lead, 1.5 per cent tin, 0.3 per cent antimony.

Heat A.—The furnace was hot from previous runs on the regular leaded bronze, but had cooled somewhat because of trouble in making contact with the lower electrode. The furnace had been tilted clear up and scraped to get out all the leaded bronze and slag that had run over the lower electrode and frozen. Five hundred and one pounds of yellow ingot, plus 10 pounds leaded bronze borings to get contact between electrode and charge, was charged, plus limestone and a little sand to form a slag. The furnace was very tightly closed by luting with fire clay about the spout plug and electrode, and very little fume escaped during the run. Current was on 1 hour and 50 minutes, but only 96 kw. was used, the power input being only an average of 52 kw.

The furnace would not take any more power than this, the arc being very short and snappy, no matter how close the graphite electrode was brought to the bath, as the power factor was amazingly low, running from 18 to 38 and averaging 33. When the metal was poured its temperature measured in the ladle was only

980° C., far too cold for pouring castings, though the metal poured into ingot without much skulling. The roof, furnace walls, spout, and back of the spout plug were covered to a depth of one-half inch with a mixture of zinc oxide and metallic zinc which had distilled out of the charge by the local overheating of the arc. When this coating was scraped in order to bare a fresh surface, it burned with the characteristic zinc flame, showing the presence of metallic zinc. Only 428½ pounds was obtained in the ladle as spillings and as large chunks in the slag. The skimmings weighed 47 pounds and were estimated to contain 75 per cent metallic or 35 pounds. The furnace was not drained completely, but certainly not over 20 pounds was left in it.

As a total of 511½ pounds was charged and 428½+35+20 pounds obtained, the net loss was about 28 pounds, or 5½ per cent.

Heats B and C.—To check up this figure two more heats were made, the furnace being hot from a heat on bearing bronze, which had been drained and scraped out till the furnace was clean.

In heat B the arc was on two and one-half hours, 108 kw. h. being used. The average power input was 43 kw., but the power factor was not taken. The metal was poured at 1,090° C. Cupola slag, glass, and limestone were used as slag. In heat C the arc was on 1 hour and 48 minutes, 84 kw. h. being used. The average power input was 52, the power factor varying from 20 to 44 and averaging 33. The metal was poured at 1,070° C. Little zinc fume escaped during the run, but vast clouds came out while pouring. In these two heats 1,017 pounds ingot was charged, and 925½ pounds were weighed up in the ladles. The furnace was scraped clean after heat C. From the skimmings 4 pounds of large chunks were picked. The balance of the skimmings, 53 pounds, contained 47 pounds metallic. Recovery, $925\frac{1}{2}+4+47=976\frac{1}{2}$ pounds; loss, 40½ pounds, or 4.4 per cent. Analyses of metal from heats B and C showed, respectively, 71.8 per cent copper, 22.3 per cent zinc, and 69.7 per cent copper, 25.3 per cent zinc; the original ingot carried 67.6 per cent copper, 27.5 per cent zinc. Compared with this 27.5 per cent, the average zinc content, 23.8 per cent of the product, indicates a loss of about 4¾ per cent.

These runs, while not giving very accurate figures, show plainly that the direct-arc furnace, causing losses of 4 to 5 per cent on yellow brass charged as ingot, can no more be considered for melting alloys high in zinc than can an open-flame oil furnace.

Smith** mentions a trial made in England during the war in which it was found impractical to handle yellow brass in a direct-arc furnace.

** FAYAT, E., *Recherches, Metal Ind.* (London), vol. 16, 1920, p. 363.

In these three heats, yellow brass was heated to an average temperature of less than $1,050^{\circ}\text{C.}$, in a hot furnace, at an average rate of 380 kw. h. per ton.

RUNS ON LEADED BEARING BRONZE.

Though the furnace was plainly useless for yellow brass, it worked better on the leaded bearing bronze, as is shown by the data below on two-day runs.

In order to keep the furnace hot it was filled with coke at night, and enough air was allowed to enter to keep the coke smoldering. The coke was scraped out the next morning. On each heat in the test given in Table 30, 600-pound charges were used. The charge was half ingot or heavy scrap, half heavy borings or gates, save in heats 2, 3, and 4 of February 10, when the charges were concentrates from ashes and skimmings from the foundry's reclaiming plant.

TABLE 35.—*Test of 600-pound Snyder furnace melting leaded bronze.*

Date.	Heat No. ^a	Power on.	Power off.	Arc on. ^b	Kw. h. used.	Temperature in ladle.
				H. m.		$^{\circ}\text{C.}$
Feb. 9.....	1	7.00 a. m..	9.06 a. m..	1 50	132	.....
2.....	2	9.06 a. m..	11.01 a. m..	1 47	132	1, 130
3.....	3	11.01 a. m..	1.00 p. m..	1 30	108	1, 170
4.....	4	1.00 p. m..	2.55 p. m..	1 40	108	1, 140
	5	2.55 p. m..	4.50 p. m..	1 48	108	1, 250
10.....	1	7.04 p. m..	9.19 p. m..	2 00	132	.....
	2	9.19 p. m..	11.12 p. m..	1 40	108	.....
	3	11.12 p. m..	1.07 a. m..	1 43	108	.....
	4	1.07 a. m..	2.45 a. m..	1 23	108	.....
	5	2.45 a. m..	4.35 a. m..	1 35	108	.....
					c 1, 150	.....

^a Total for 10 heats, 6,000 pounds.

^b Average time on, 1 hour and 46 minutes.

^c Average, 383 kw. h. per ton.

In the test in January, when an operator was on the job who maintained a higher power input, and hence only averaged 1 hour and 36 minutes for the time the arc was on per heat, and the metal was poured with little delay, so that six heats were made per 10-hour day; the average of several days was 350 kw. h. per ton.

In 27 heats, with the regular bearing-metal charge, 15,468 pounds were charged and 15,138 pounds metal were weighed in the ladles, a gross loss of 2.13 per cent; 431 pounds slag contained 7 per cent copper and was calculated to contain 5 per cent recoverable metal, or $21\frac{1}{2}$ pounds, making the net loss 1.99 per cent.

In 17 later heats of the regular bearing-metal charge (heats on concentrates not being considered) on which data were taken by the bureau's representative, 9,978 pounds were charged and 9,767 pounds were weighed in the ladle; and 281 pounds slag were obtained, estimated to contain 14 pounds recoverable metallic, a gross loss of 2.12 per cent, or a net loss of 2 per cent.

From this 2 per cent net loss should be deducted about $\frac{1}{2}$ per cent nonmetallic in the charge, leaving the true net loss 1.5 per cent. The net losses, not deducting for nonmetallic in the charge, on the same material melted in the other furnaces at this plant, were said to be:

	Per cent.
Oil-fired crucible lift-out furnace.....	2 $\frac{1}{2}$
Tilting crucible, forced draft, coke.....	2 $\frac{1}{2}$
Open-flame oil.....	5 $\frac{1}{2}$

Out of the 5 $\frac{1}{2}$ per cent in the open-flame oil furnace 3 per cent represents extra lead added in the ladle to compensate for the lead burnt out or volatilized in the open-flame furnace to make the product analyze the same as that from the crucible furnaces.

On account of slag formation in the open-flame furnace and of much charge being dropped into the ashes in the coke furnace, from which it had to be recovered in the reclaiming plant, the distribution of the metal charged to the different furnaces was as follows, according to the plant records:

TABLE 35. *Distribution of metal charged.*

Furnace.	In crucible or ladle.	For recovery in slag or ashes.	Lost.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Crucible lift-out oil.....	95	2.5	2.5
Crucible tilting coke.....	85	12.5	2.5
Open-flame oil.....	90	4.5	5.5
600-pound Snyder.....	97.9	.1	2.0

In the crucible tilting coke furnace much of the heavy gross loss was due to spilling the charge outside the crucible into the coke in charging.

The 600-pound furnace ran smoothly, was kept tight by luting the spout and the space around the electrode so that the furnace did not give off much fume, was much cooler, and was less irksome generally to operate than fuel-fired furnaces. The power factor of the furnace was uniformly low, and varied greatly with the conditions of operation, particularly with the nature of the slag.

The slag used in the yellow-brass heats was not fluid, but crusty, and was raked off rather than skimmed. In the regular bearing-metal heats, in which limestone in walnut or large size was added to form a slag with the small amount of sand on the gates and with the sand and dirt swept up with the spillings, the slag was also more crusty than fluid. The addition of limestone gave a good fluid slag in a few heats on melting concentrates, from the reclaiming plant, that carried slag from the open flame oil furnaces and ash from the coke furnaces. The variation in power factor is shown below:

TABLE 37.—*Variation of power factor in melting different materials in 600-pound Snyder furnace.*

Material.	Average kw.	Average kv. a.	Average power factor.	Lowest power factor.	Highest power factor.	Slag.
Yellow brass.....	45	136	33	18	44	Crusty
Bearing metal.....	70	126	55	27	68	Do
Concentrates.....	69	96	72	55	89	Fluid.

In an atmosphere of zinc or lead vapor and with a crusty slag, which probably causes the arc to play directly on metal rather than on slag, the power factor obviously is amazingly low, whereas in melting concentrates, which are practically free from zinc and low in lead, with a fluid slag that can produce arc-supporting vapor, as in a direct-arc furnace operating on steel, the power factor, though low, could be tolerated.

The plant decided that a 600-pound furnace was too small a unit. The test indicated, however, that the installation of 1-ton furnaces, especially if they were run 20 to 24 hours a day, would effect notable savings through the elimination of crucibles and the reduction of metal losses; the crucible furnaces, therefore, were replaced by two 1-ton Snyder furnaces, and two 1-ton Rennerfelt furnaces were added later. The open-flame oil furnaces continue to be used when the demand for metal exceeds the capacity of the electrics, or when an electric is down for relining; but the great bulk of the production comes from the electric furnaces.

The Chicago Bearing Metal Co. makes large railroad-car bearings, used as backing for babbit liners; on these bearings considerable variation in composition is allowable and they have to pass no severe tests. The question of improved quality in their manufacture was not paramount, as the open-flame oil furnaces produce metal of satisfactory quality for the purpose. Under these conditions the usefulness of the furnace lies almost entirely in quicker production, the principal and almost the sole aim in the operation of furnaces being large output.

Two single-phase 1-ton furnaces with 700-kv. a. transformers, built on the same general design as the 600-pound furnace, were installed, but it was found that on some points their action was not quite like that of the smaller furnace. Figure 23 shows the design of the single-phase furnace.

It proved impossible to lute the spout and electrode tightly enough to prevent the escape of metal vapors or to prevent the entrance of air. The pressure developed inside the furnace was so great that the luting was blown out; if the luting were held in place mechanically the bricks in the roof were loosened until sufficient vent was made for the vapor to escape.

The furnaces have regularly been run with the spout plugged loosely, if at all, and with plenty of clearance about the electrodes. As a result the metal losses have been greater than was indicated

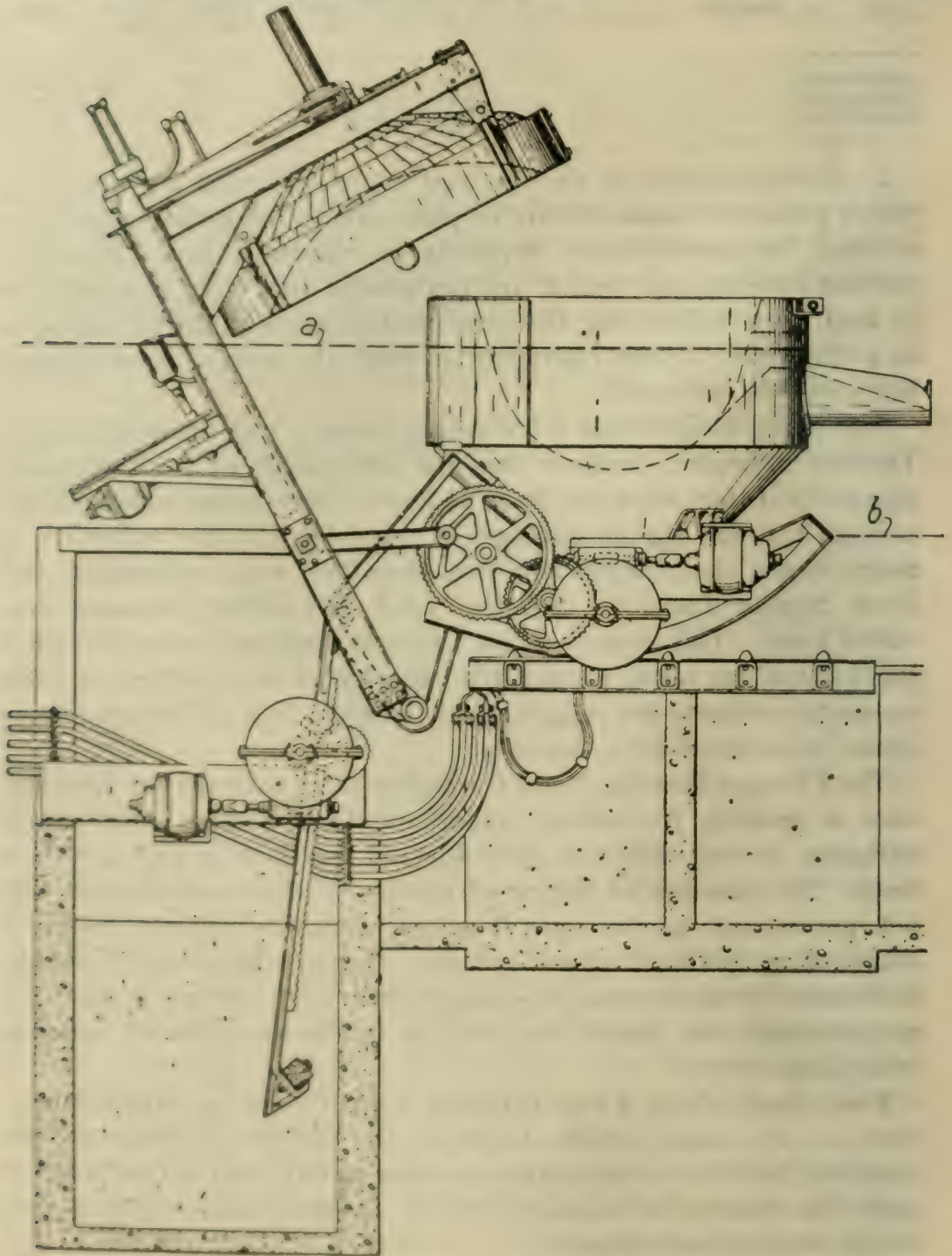


FIGURE 22.—Snyder direct-arc furnace: *a*, charging-floor line; *b*, foundry floor.

by the test of the small furnace and the working conditions as to fume and smoke have been much worse than with the open-flame oil furnaces. It has been necessary to install hoods and fans to withdraw the fumes in order to avoid danger from lead poisoning;

in the first few weeks' operation of the large furnaces several workmen were seriously, though temporarily, affected by the lead and antimony fume.

IMPROVEMENTS IN SNYDER FURNACE.

Inasmuch as power is purchased on a schedule calling for a penalty when the power factor of the total supply to the plant is under 70, and as the average power factor of the Snyder furnaces has been much below that figure, constant effort has been made to improve the power factor. An attempt at improvement was made soon after the installation of the furnaces by removing from one furnace most of the reactance that had been put into the transformer to stabilize the arc. In consequence the furnace drew such an excess of power that an almost new silica-brick roof was melted down promptly. Part but not all of the reactance was then replaced. This reduction in reactance raised the power input that could be conveniently held to about 420 kw. instead of 360 kw., which was all that could be conveniently held when the original reactance was in use. Most of the later attempts at improving the power factor dealt with the furnace itself and its method of operation rather than with the reactance of the circuit. The furnaces use an open-circuit voltage of about 205, which drops under load to an arc voltage that varies from 100 to 160 volts, depending on the position of the electrode and the resulting length of the arc, but averages about 130.

Until recently the furnaces were hand operated. An arc long enough to draw the higher voltage can not be readily maintained while the cold charge is melting down, especially if the charge is mostly made up of large chunks such as ingot or of scrap bearings. If a considerable percentage of borings, concentrates, or other small pieces is present, a pool of molten metal is more readily formed and the maintenance of an arc at the higher voltage is possible.

The operator can hold the arc at 145 volts if he gives it constant attention, but owing to the inherent reactance in the circuit and to that in the furnace transformer if he sets the arc at a length where it will burn steadily with little or no hand regulation this length draws 125 to 130 volts. St. John⁷⁰ gives a curve showing that at 110 volts the power factor is 47, at 125 it is 55; if the arc voltage is held up to 160, the power factor rises to 68.

In the regular running of the hand-operated furnace the voltage averages 125 to 130 and the power factor 55 to 56. This power factor is so low that it involves an expensive penalty in the power bill. The motor load, and especially the use of the Rennerfelt furnaces, which have a power factor well above 70, increase the total plant

⁷⁰ St. John, H. M., Commercial testing of metallurgical electric furnaces: Chem. and Met. Eng., vol. 21, 1919, p. 383.

power factor so that the penalty is much less than it would be if the electric furnaces were all Snyders.

By the use of plenty of coke on the surface of the melt, so that the arc was drawn between the graphite electrode and the coke, instead of between the electrode and the metal, the amount of metal vapor in the arc was reduced, the arc length increased, and the voltage raised so that a power factor of 73 could be obtained. The practice was not adopted because of the contamination of the metal by the sulphur in the coke.

The use of crushed electrode scrap, which would be free from sulphur, has been suggested, and obviously is worth trying, but so far as is known has not been tried out. The first furnace, rated at 1 ton, was at first given charges of 3,000 pounds, and turned out about 10 heats, or 15 tons in 24 hours, at a power consumption of around 315 kw. h. per ton, with a power factor of about 55. The electrode consumption was about 5 pounds per ton. The first linings of fire brick or rammed in carborundum, coke dust, and fire clay had a very short life.

On 24-hour tests of the 1-ton Snyder furnaces made in 1917 with hand operation one furnace made 38 heats of 2,000 pounds each in 48 hours at an average power consumption of 285 kw. h. per ton; average power factor, 56; the other made 40 heats in 48 hours, at an average of 290 kw. h. per ton. One furnace made 10 consecutive heats in 11 hours and 40 minutes, at an average power consumption of 271 kw. h. per ton, varying from 254 to 288. Four consecutive heats were made at an average of 261 kw. h. per ton. This period was exceptionally free from delays, such as waiting for the crane to handle the ladles, only 25 minutes being occupied by anything other than charging, pouring, or melting. The furnace ran at an average power input of 400 kw., an average voltage of 121, and an average power factor of about 53.

Throughout the whole test (52 heats, 65 hours) of the furnace the power consumption averaged 285 kw. h. per ton. The arc was on 57 per cent of the time; 20 per cent was occupied in pouring, charging, and pulling slag; 6 per cent was lost through electrode troubles, mainly breakage due to poorly fitting joints; 3 per cent through trouble with the tilting motor; and 14 per cent through delays not due to the furnace itself.

By eliminating avoidable delays it should be possible to make 21 heats in 24 hours, at 270 kw. h. per ton, on this leaded bearing metal, poured at about $1,150^{\circ}$ C. ($2,100^{\circ}$ F.). This large production is due in part to the high power input, about 400 kw., and in part due to the rapid mechanical charging made possible by the design of the furnace roof, which may be raised rapidly and tilted back to open

completely the top of the furnace, and the charge may be dumped in from a bucket or clam shell without any handwork save a little poking to arrange the charge.

METAL LOSSES.

Metal losses were determined on 42 heats of this test, though not with a great degree of accuracy. The net loss was about $4\frac{1}{2}$ per cent; that is, much greater than the loss with the smaller furnace, more than on fuel-fired crucible furnaces, and only 1 per cent below that given by the open-flame oil furnace. This loss is due obviously to volatilization of lead and antimony, the latter being an impurity arising from the use of scrap hard lead as a part of the charge in the making of the bearings. Any lead to be added to the charge is not put into the furnace but is added in the ladle.

The metal losses on the whole year's operation of the Snyder and Rennerfelt furnaces together, calculated on an inventory basis, were somewhat lower than those found in the tests, and though the Rennerfelts are conceded to give somewhat lower metal losses than the Snyders, thus reducing the figures of metal loss when the results of both types of furnace are lumped, it is doubted whether this difference is enough to give the inventory figure if the average loss with the Snyders was as great as indicated by the tests. It therefore seems probable that the net loss for the Snyders is between 3 and 4 per cent rather than above 4 per cent.

The fact that lead may be volatilized from copper by a direct arc is utilized by Hill and Luckey⁷¹ for rapid determination of the lead content of copper. They play a 220-volt arc 0.5 cm. long, at 10 amperes, on 0.4 gram of copper, observe the arc spectrum through a spectroscope, and record the time required for the lead lines to disappear. This time is proportional to the lead content of the copper. In two minutes 0.016 per cent lead disappears, and in eight minutes 0.216 per cent.

It is not surprising then that a direct arc playing on an alloy with, say, 15 per cent lead should cause a distinct loss of lead.

According to figures from the Chicago Bearing Metals Co., in 49 working days (two shifts of nine and one-half hours each) in December, 1917, and January, 1918, the two Snyder furnaces together melted 2,600,000 pounds, or about $13\frac{1}{2}$ heats of one ton each per furnace per 19-hour (two-shift) day.

The average cost of materials used for relining the Snyder furnaces for three months, exclusive of labor, was $21\frac{1}{2}$ cents per ton. The roofs were made of fire brick, the hearths (rammed in) of a

⁷¹ Hill, C. W., and Luckey, G. P., The spectroscopic determination of small amounts of lead in copper: *Trans. Am. Electrochem. Soc.*, vol. 32, 1917, p. 335; *Met. and Chem. Eng.*, vol. 17, 1917, p. 659.

mixture of four parts carborundum fire sand, two parts fire clay, and one part molasses. The labor charge would probably make the cost about 35 cents per ton.

REPAIR COSTS.

The average electrode consumption for three months was 2.9 pounds per ton, which does not include losses from breakage, the broken pieces being used as stock for machining nipples for the Rennerfelt electrodes. On a one-week test, in which 163 tons were melted, 573 pounds were actually consumed and 159 pounds broken pieces were set aside as nipple stock. The total consumption was then $4\frac{1}{2}$ pounds per ton; aside from breakage, $3\frac{1}{2}$ pounds per ton. At 3 pounds per ton, at the 1918 price of 25 cents per pound for graphite electrodes, the electrode cost is 75 cents per ton. No water-cooled ring such as is common on steel furnaces is used where the electrode enters the roof, so that the electrode becomes red-hot for some distance outside the furnace and burns away on the surface above the roof. Suitable water-cooling or a suitable "economizer"⁷² at the point of entrance might reduce the electrode consumption. The total cost of upkeep for refractories, the labor in relining, and for electrodes was therefore about \$1.10 per ton.

DATA ON OPERATION.

In April, 1918, through the courtesy of the Chicago Bearing Metal Co., a representative of the Bureau of Mines was permitted to take the data on the regular operation of the Snyder furnaces while melting about 140 tons of metal. Fifty-two heats were run in one furnace in four days each; heat was 1 ton (except one 1,500-pound heat) of leaded bearing bronze and 13 heats were melted in about 19 hours (two $8\frac{1}{2}$ hour shifts), 103,500 pounds were melted with 14,460 kw. h., or 278 kw. h. per ton. If the first two heats made after the cooling period between shifts be excluded, to compute results on a 24-hour basis, the power consumption required was at the rate of 265 kw. h. per ton.

On 34 heats, from 67,500 pounds of the leaded bearing metal, less 147 pounds estimated nonmetallic, or 67,453 pounds metallic charged, 64,911 pounds were poured (weighed in the ladles), giving a gross loss of 3,442 pounds or 5.1 per cent. The 2,526 pounds slag, estimated by the Chicago Bearing Metal Co. as 25 per cent recoverable metallic, reduce this loss to 2,810 pounds, or to 4.15 per cent net loss.

In the other furnace, for 36 heats of 1 ton each of leaded bearing metal, three days' run, 12 heats, averaging about 18 hours, 72,000

⁷² *ABSTRACTS*. Twelve coils gas around furnace electrodes: Foundry, vol. 48, 1920, p. 281.

pounds total were melted with 11,050 kw. h., or 306 kw. h. per ton. The reason for power consumption being more in this furnace than in the other is partly the shorter running time and partly the larger delays, not due to the furnace. It is also probable that the average pouring temperature of the output of the second furnace was somewhat higher.

The average of both furnaces for 88 heats was 290 kw. h. per ton on 18 to 19 hour two-shift operation. While the arc was on the average power input was about 310 kw. The average power factor on a week's test, made by the meter department of the Commonwealth Edison Co. at this time, was 35 for one Snyder furnace and 37 for the other. As these furnaces were designed to give a power factor of about 70, it seems probable that part of the low power factor resulted from the arc containing the vapor of volatile metals such as lead or zinc.

A power factor of 36 was obtained in this 1918 test, one of 55 in the 1917 test, and one of 50 in the 1919 test. The effect of these factors on the cost of operation can be realized by noting that power was bought under a contract having the usual demand charge, in this case \$1 per month per kw. maximum demand, as shown by the demand meter, plus an energy charge of about 1.21 cents per kw. h. for the first 30,000 kw. h., 0.68 cent for the next 70,000 kw. h., and about 0.50 cent for power above a total of 10,000 kw. h. If the power factor under average operating conditions is under 70, it is provided that the demand charge shall be multiplied by 70 and divided by the actual average power factor. The average demand of the two Snyder furnaces together is, say, 600 kw.

TABLE 38.—*Effect of power factor on cost.*

Power factor.	Monthly demand charge.	Excess monthly cost from low power factor.	Excess yearly cost for two furnaces.
70 or over.....	\$600.00		
55.....	$600 \times \frac{70}{55} = 763.63$	163.63	\$1,963.56
50.....	$600 \times \frac{70}{50} = 840.00$	340.00	4,080.00
36.....	$600 \times \frac{70}{36} = 1,166.66$	566.66	6,800.00

Suppose the two furnaces produce metal at the rate of 30 tons a day on 24-hour operation, 20 tons a day on 19-hour, two-shift operation, or 10 tons a day on 8½-hour, one-shift operation, the output per furnace per year of 300 working days would then be as follows: 24 hours, 9,000 tons; 19 hours, 6,000 tons; 8½ hours, 3,000 tons.

TABLE 39.—*Yearly excess cost from low power factor.*

Power factor.	Excess cost per furnace a year.	Approximate excess cost per ton a year.		
		24 hours.	19 hours.	8½ hours.
70.....	None.	None.	None.	None.
55.....	\$881.78	\$0.10	\$0.15	\$0.30
50.....	2,040.00	.23	.34	.68
35.....	3,400.00	.38	.57	1.13

In 1918 the Chicago Bearing Metal Co. was using the two Snyder and two Rennerfelt furnaces two shifts, and three 2,600-pound capacity open-flame oil furnaces one shift, on leaded bearing bronze. A few small oil-fired crucible furnaces were running one shift on yellow brass and manganese bronze, no attempt being made to operate the electric or the open-flame furnaces on these high-zinc alloys because of the metal losses being higher than in the crucible furnaces.

IMPROVEMENTS.

In 1919 General Electric (Seede) regulators were put on the two Snyder furnaces in order to save labor, one man (with help during charging and pouring) operating two furnaces, whereas with hand regulation one man was required per furnace. It was hoped that the average rate of power input would be increased and the power factor raised by holding a longer arc and hence taking a higher arc voltage than with hand regulation. It was found possible to hold a higher power input, so high in fact that the transformers would not withstand, without undue heating, the rate of power input that gave maximum output and thermal efficiency. In 52 days of nine hours each one Snyder furnace melted 952,441 pounds, or 476 tons, in 458 hours; the other Snyder furnace melted 874,000 pounds, or 438 tons, in 465 hours. Both furnaces together produced 904 tons in 923 hours, or about 1,950 pounds per hour, running single shifts of nine hours, with automatic control of electrodes. The power consumption was reduced to about 300 kw. h. per ton for the leaded bearing metal; that is, almost to the 1917 figure for 24-hour operation with hand control of the arc. This power input had to be reduced in order to safeguard the transformers, so this low power consumption could not be continued.

The roofs, made of cheap fire brick, last 90 to 140 heats, spare roofs being kept on hand. The rammed-in carborundum and fire-clay hearth lasts about 200 heats.

The power factor can be maintained at 50 to 55, but to raise it above those figures has not been possible, although expert electrical engineers attempted to improve it,

The makers of the Snyder steel furnace have put a two or three phase, lower voltage type of furnace on the market, which gives a higher power factor on steel than the older form of single-phase, high-voltage Snyder. Undoubtedly it is possible to find some way of constructing a direct-arc furnace and operating it on bronze or red brass so as to have a power factor high enough to avoid penalties, but so few attempts have been made to apply true direct-arc furnaces to copper alloys, high-voltage Snyder furnaces being the only example of the direct-arc type commercially melting such alloys in this country, that data on the best methods of doing this are lacking. It seems probable that the task would be less difficult in melting a true bronze, neither copper nor tin being very volatile, than in melting alloys containing much lead, antimony, or zinc, all of which are decidedly volatile at arc temperatures and tend to make an arc stream that is largely metallic vapor rather than carbon vapor.

Although the metal losses in any direct-arc furnace running on yellow brass are prohibitive and are high in the 1-ton Snyder, even on leaded bearing metal, owing to the impossibility of luting the furnace and running it tightly closed, the users consider that the metal losses are at least 1 per cent lower than for open-flame oil furnaces melting the same charge.

The field of the direct-arc furnace is seen to be very small, only that of melting alloys with very little or no zinc, and the furnace is handicapped by the metal losses on alloys high in lead. Its reliability is only fair, for the life of roof and lining is not very long; to balance this disadvantage is the possibility of putting a spare roof in place without much delay.

Because it can be charged rapidly by opening the roof and because of the relatively high power input for the 1-ton furnace, the Snyder furnace has so high a thermal efficiency and so great a rate of production that under the conditions in which it has been used it has shown lower melting costs than crucible or open-flame melting, even though the metal losses were high.

The electrical characteristics of the old-style Snyder furnace are poor, as the 1-ton furnace, taking 300 to 400 kw. at 50 to 55 power factor, draws a load of about 700 kv. a., and to avoid current disturbances to other power users on the same line it has to be put on a separate line. The excessively low power factor involves a penalty that, on single-shift operation of the furnace, may amount to an excess power charge of over \$1 per ton. Because of the large production and the use of automatic regulators the labor cost per ton is low.

The price of the 1-ton single-phase furnace or of the more modern two-phase furnace, with automatic electrode control and all auxiliary

transformers, switches, switchboard, and meters, except a watt-hour meter, on January 19, 1920, was \$17,000. For a single-phase hand-operated furnace without automatic electrode control the price was \$16,000.

WILE FURNACE.

In 1912 another furnace, the Wile, was advertised for use in brass melting, though intended primarily for smelting tin dross, melting gold concentrates, etc.⁷³ At the plant of the Great Western Smelting and Refining Co., St. Louis, some 10 years ago one of these furnaces was tried for smelting lead and tin drosses, but was not considered satisfactory and was not put into regular commercial operation. About the same time both the tilting and tapping forms were also tried out on silver at the plant of Handy & Harmon, Bridgeport, Conn., with unsatisfactory results and were not used for commercial work.

The furnace was planned to melt brass with a deep slag or molten glass, and the heating was from the resistance of the slag alone if the furnace is operated at a low voltage, with the upper electrode or electrodes buried in the slag. If operated at a higher voltage, with the electrodes not touching the slag, but drawing arcs to it, the heating is due to a combination of arc and slag resistance. One of these furnaces was used for a time by the Westinghouse Electric and Manufacturing Co. in melting cast iron for making cast resistance grids. The furnace used 200 to 300 pounds of glass slag for a 100-pound charge of cast iron and had to be run with the electrodes arcing to the slag and not buried in it. The arc heating, in this case at least, clearly overbalanced the resistance heating, and the furnace seems classifiable more properly under arc furnaces than under resistor furnaces.

The furnace is similar in principle to the general run of ferro-alloy smelting furnaces, such as those for ferromanganese. In these the charge is manganese ore, flux, coke, and metallic iron if not enough is present in the ore; the manganese, reduced from the ore in the reaction zone and alloyed with the iron, drops through the slag layer into the layer of fused alloy below. From time to time slag and metal are tapped and more charge is added, the furnace operating continuously. Such smelting furnaces are efficient and suitable for the work they have to do, but they are *smelting* furnaces, not *melting* furnaces, and are designed to heat the solid charge or the molten slag rather than the lower layer of fused metal.

⁷³ Wile, R. S., An electric furnace for the treatment of tin dross: Met. and Chem. Eng., vol. 18, 1912, p. 403; Reduction of tin drosses in an electric furnace: Trans. Am. Electrochem. Soc., vol. 18, 1910, p. 263; The Wile furnace: Trans. Am. Electrochem. Soc., vol. 28, 1914, p. 257; U. S. Patents 947,722, Jan. 25, 1910, and 1,070,568, Aug. 19, 1913.

It was reported that a Wile tapping shaft furnace, with a conducting bottom and one or two upper electrodes extending into the slag layer, was used for a time in smelting concentrates from brass furnace ashes, dirty brass borings, etc., the furnace operating much like an electrically heated cupola. No data on its operation has been obtained. It may have run on a commercial scale, but if so its operation was not long continued.

The Wile⁷⁴ melting furnace advertised for brass was a tilting furnace having a furnace shell mounted to tilt on trunnions, and it has a "teakettle" spout for pouring the metal from beneath the slag and retaining the hot slag in the furnace for the next heat. In the single-phase form two upper electrodes, in series, project through the roof and directly underneath are two lower electrodes, also electrically connected. In starting the cold furnace arcs are drawn from the upper electrodes to the lower ones until the glass is melted. The lower electrodes are short-circuited by the molten metal and no appreciable current flows through them.

One of these furnaces was installed, for instruction purposes, at the Carnegie Institute of Technology. In 1912 two qualitative runs of this furnace were made by D. A. Lyon of the Bureau of Mines.

The furnace was rated to hold 500 pounds of brass, but the power supply available was only 50 kw. In the first run it took $1\frac{1}{2}$ hours and 72 kw. h. to melt the glass slag ready to run; 22 pounds of scrap red brass were then charged and in 45 minutes 31 kw. h. were used. During this run much zinc oxide was emitted from the furnace. The metal could not be poured cleanly, free from slag, so the slag was poured also; 17.8 pounds of ingot were poured. On grinding and concentrating the slag $4\frac{1}{2}$ pounds of brass shot were obtained. The slag contained 3.6 per cent zinc; 0.7 pound of metal, or about 3 per cent, was lost.

After this run fresh glass was charged into the hot furnace. It took two hours and 91 kw. h. to get the glass melted and fully fluid.

Twenty-three pounds of copper were charged and 25 kw. h. more were supplied to the furnace. The power was then cut off and 13 pounds zinc added in small pieces at intervals. Explosions took place as each piece passed through the superheated slag and clouds of zinc fume were evolved. About 15 kw. h. more were supplied and an attempt made to pour, but only 6.3 pounds ingot were obtained. The slag contained 9.4 per cent zinc.

A further test was made by one of the writers in January, 1913, to study the behavior of the furnace. As Mr. Wile could not be present

⁷⁴ Wile, R. S., An electric furnace for the treatment of tin dross: *Met. and Chem. Eng.*, vol. 10, 1912, p. 495.

and sent no directions, the furnace was operated on the basis of his previous verbal instructions to Mr. Lyon.

The chrome-brick lining had been considerably eroded in the previous runs, but was patched up with magnesite cement. The furnace was started on about 150 volts and about 80 pounds of broken window glass was fed in slowly. It took 1 hour and 50 minutes and 67 kw. h. to melt the glass. In order to get the furnace to take 45 kw. it was necessary to run short arcs to the slag. When charging was begun the furnace took 150 volts, 300 amperes; 94.3 pounds of leaded bronze containing 6 to 7 per cent tin, 10 to 12 per cent lead, $1\frac{1}{2}$ to 2 per cent zinc, the balance copper, was charged in the form of ingots weighing about 15 pounds each. Each ingot was allowed to melt before the next was added in order to avoid freezing the molten mass. All the charge was added in 40 minutes, and heating was continued 20 minutes more. Sixty-seven kw. h. were used in 1 hour and 10 minutes. The metal was then poured, but could not be poured cleanly from the slag; everything was poured into ingot molds and the slag was later broken off. Eighty-seven and nine-tenths pounds of ingot were obtained and one-half pound more as buttons by crushing and jiggling the slag. The net metal loss was 5.9 pounds, or over 6 per cent. The slag contained chromium from the chromite lining. The power factor averaged about 94. The electrodes lost $3\frac{1}{2}$ pounds during the run.

Very unpleasant fumes were evolved while the glass was being melted by the arcs, the lining was eroded by the slag, and the metal, except in the middle of the pour, could not be poured reasonably free from slag; the first and last metal were badly mixed with the slag.

Mr. Wile later said that the tilting type had been abandoned in favor of the tapping type. Though the test could not give any direct evidence on power consumption, it did indicate that melting the glass on 10-hour operation, for example, would take so long and use so much power to melt the glass that the furnace would be inconvenient and impractical.

If the solid material charged floated on the molten material, or if it could be held in the slag until it melted, as in ore-smelting furnaces, an arc-slag resistance furnace might be thermally efficient; in melting brass, however, the solid material charged sinks under the molten slag and goes to the bottom of the molten metal, if any is molten. The heat generated above or in the slag is applied therefore by conduction only to the metal, and slag is a relatively poor conductor of heat. Wile furnaces have been suggested for melting steel, but

Cone⁷⁵ says that the Wile furnace has disappeared altogether from the list of active steel furnaces.

A Wile furnace was erected at the plant of the Tottenville Copper Co. in 1919 "to make experiments on certain alloys, but it did not give satisfaction, is not now in use, and has been dismantled."⁷⁶

The Haynes Stellite Co.⁷⁷ tried a Wile furnace for melting Stellite, but found the molten glass too destructive to the lining.

BENNETT FURNACE.

The Bennett furnace, the next on the list, is structurally similar to a direct-arc furnace, but is not an arc furnace because the voltage between electrode and bath is kept so low that no true arc is formed. Heat is generated by the resistance of a poor contact between electrode and metal.

The Bennett furnace has been described only in the patent,⁷⁸ and the patent describes the process rather than the furnace. Other applications on important features are still in the Patent Office. The furnace has been developed at and for the Scoville Manufacturing Co., Waterbury, Conn., and has been operating commercially for several years. Six 1-ton furnaces and one 5-ton furnace are melting alloys ranging from yellow brass to copper. The 5-ton furnace is the largest electric furnace yet built for brass.

The Bennett furnace was adopted after exhaustive experiments with many other types; hence its selection and use by the Scoville Manufacturing Co. indicate that it is suitable for nonferrous melting. It has not yet been decided, however, whether or not the furnace will be made available for other users; unless and until the furnace is put on the market it is likely that the present policy of secrecy as to the exact design of the furnace and as to its performance will be maintained.

According to the patent the furnace is three-phase, the 1-ton size taking 2,500 amperes per electrode at a voltage of from 18 to 20 between each electrode and the charge, and the 5-ton furnace taking 4,200 amperes and 32 to 40 volts. In a three-phase furnace, with the probable power factor of a furnace of this type, this figure amounts to a power input of about 150 kw. in the 1-ton and 500 kw. in the 5-ton.

An arrangement of the electrodes similar to that used in the Heroult steel furnace is advised in order to effect the slight circulation of the metal and the mixing of the charge that can be obtained by utilization of the electromagnetic field. That the cir-

⁷⁵ Cone, E. F., The status of the electric steel industry: Iron Age, vol. 105, 1920, p. 75.

⁷⁶ Personal communication, Jan. 8, 1920, from Tottenville Copper Co.

⁷⁷ Personal communication, Feb. 12, 1920, from Elwood Haynes.

⁷⁸ Bennett, M. H., U. S. Patent 1,337,305, Apr. 20, 1920.

culation in the Heroult is not enough for mixing steel containing difficultly alloying elements has, however, been pointed out by Hess,⁷⁹ and this would not be sufficient to avoid local overheating.

Bennett lays great stress on holding the rate of power input down to a point where the thermal conductivity of the charge can take care of and distribute the heat without causing excessive local superheating near the electrode tips. The rate of power input used is about half that used in furnaces of similar sizes in other types. The ratio of heat lost by radiation to that usefully employed will therefore be high, and the efficiency will probably not be high, though the generation of heat in contact with the charge itself gives less chance for thermal loss than in many other types of furnace, as this factor makes for efficiency. On the other hand, the use of lower voltages and higher currents than are required by most types means a greater loss of heat in electrodes and leads.

Figure 24 shows the furnace as described in the patent, but the diagram probably represents the form actually used only as closely as was deemed necessary for the purposes of the patent.

The electrodes are probably controlled automatically by electrical devices which maintain the electrodes at such a distance from the charge that the desired voltage value is not exceeded. The auxiliary electrode shown in the tap hole does not carry power but allows connection of meters and control devices in order to maintain the proper voltage between the true electrodes and the bath. It is easy to see how the furnace can operate in this way after the charge is molten, but some difficulty might be expected in its operation on solid material before the charge has melted.

The furnace is said to operate without a slag, to be tightly closed, to be charged at the start with the whole charge, including the zinc, and to give a net metal loss of less than 1 per cent, even on alloys high in zinc and lead. The power consumption is said to compare favorably with many of the other commercial electric brass furnaces.

The furnace is of much interest theoretically, and the fact that it has operated under rolling-mill conditions in commercial production indicates that it has future commercial possibilities.

The generation of heat at voltages lower than are commonly supposed to be necessary to hold an arc on alternating current is not entirely unknown.

⁷⁹Hess, H. L. Electric furnaces as applied to steel making: *Mech. Eng.*, vol. 41, 1919, p. 141; *Chem. Abstr.*, vol. 14, 1920, p. 16.

SCHEMMANN AND BRANN FURNACE.

The Schemmann and Bronn⁸⁰ furnace for melting ferromanganese for addition to steel operates as a contact-resistance furnace. The patent states that arc furnaces operating at the usual voltage of

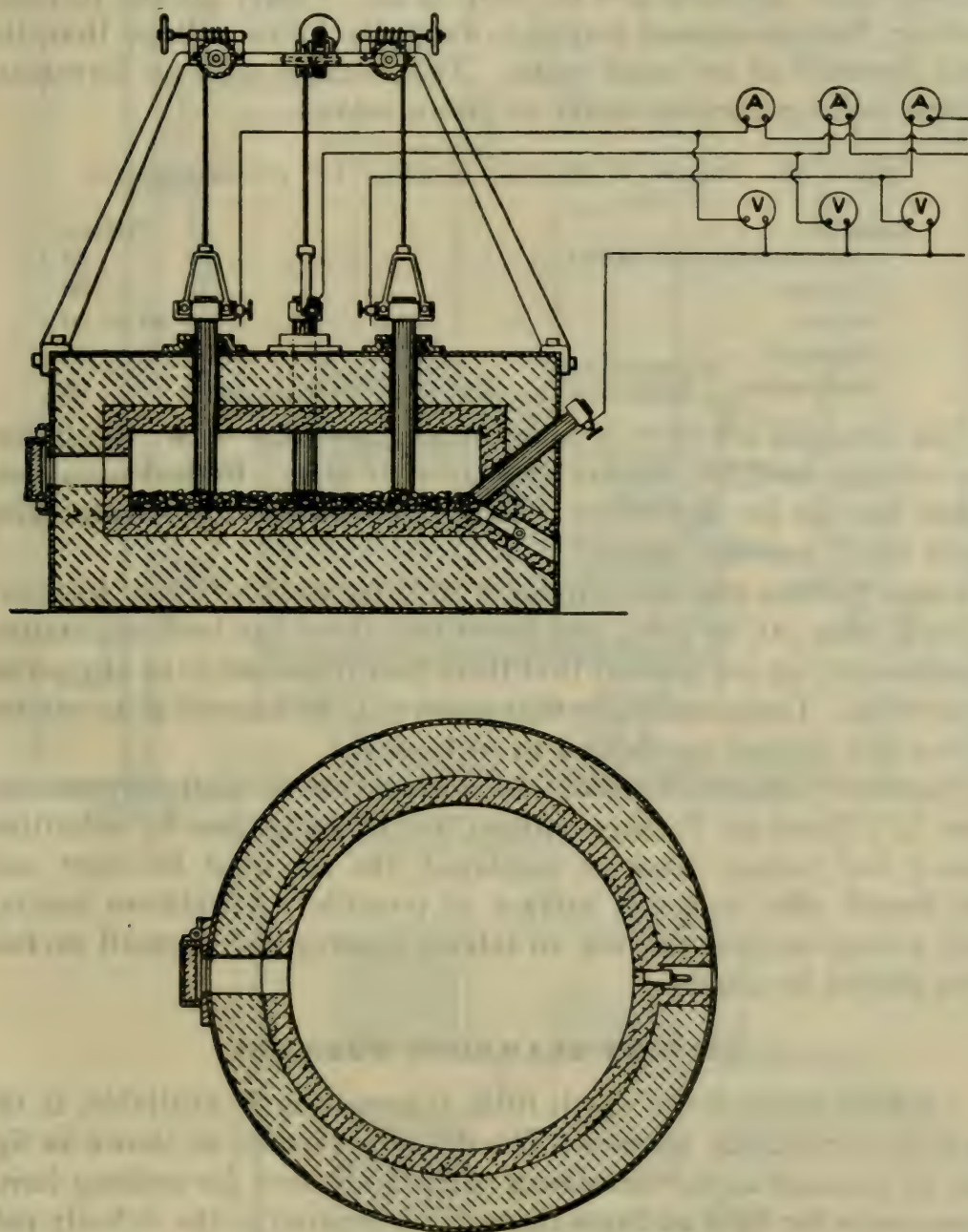


FIGURE 24.—Diagram of Bennett furnace.

steel furnaces—that is, 45 to 75 between electrode and bath—cause volatilization of manganese; if, however, the electrode is lowered so that it just touches the surface of the bath and the voltage is 16 to 18—that is, below the counter electromotive force of the arc, which is generally taken to be about 30 volts—it is possible to ob-

⁸⁰ Schemmann, W., and Bronn, J., U. S. Patent 1,056,456, Mar. 18, 1913.

tain, by the contact resistance thus produced, an ample heating of the bath without noticeable loss of manganese.

According to Rodenhauser⁸¹ the Schemmann and Bronn furnace is built much like an ordinary three-phase Heroult, but the voltage between each electrode and the bath is 25. Nearly all the furnaces melting ferromanganese run at a distinctly lower voltage than the steel furnaces of the same make. The voltages used on ferromanganese melting furnaces differ as shown below:

TABLE 40.—Voltage of electric furnaces for ferromanganese.

Furnace:	Voltage.
Schemmann and Bronn-----	25
Keller-----	30
Giroud-----	40 to 50
Heroult-----	45 to 55
Nathusius-----	65

The furnaces all carry a layer of slag over the bath; the higher the voltage used the thicker the layer of slag. Rodenhauser considers that an arc is present even at 25 volts, the arc stream being made up of metallic vapor.⁸²

Lemp⁸³ states that on automatic welding machines arcs less than $\frac{1}{16}$ -inch long can be held, and sometimes there has been maintained continuously an arc so short that there hardly seemed to be any actual separation. Lemp concludes that much is to be learned as to current action and current conduction in such an arc.

Bardwell⁸⁴ quotes Korten⁸⁵ as stating that to melt ferromanganese in a direct-arc furnace without loss of manganese by volatilization a low voltage must be employed, the arc must be short, and the hearth offer as much surface as possible. A uniform heating over a large surface and not an intense heating over a small surface area should be sought.

DENOLLY-GRAMMONT FURNACE.

Another furnace, on which little information is available, is the deNolly-Grammont furnace. The deNolly furnace as shown in figure 25 was used at the Grammont works in France for melting ferromanganese for fluid addition to steel. According to the deNolly pat-

⁸¹ Rodenhauser, W., *Ferromangan als Desoxydationmittel*, 1915, p. 26.

⁸² Compare McLennan, J. C., *Low-voltage arcs in metallic vapors*; *Proc. Phys. Soc.*, vol. 21, 1919, p. 39; *Chem. Abstr.*, vol. 13, 1919, p. 2311.

⁸³ Lemp, H., discussion *Welding mild steel*; *Bull. Am. Inst. Min. Eng.*, May, 1919, p. 829.

⁸⁴ Bardwell, F. S., discussion *Bull. Am. Inst. Min. Eng.*, No. 143, Nov., 1918., p. 1652.

⁸⁵ Korten, R., *Stahl und Eisen*, vol. 32, 1912, p. 426.

ent⁸⁶ this furnace also bears much resemblance to a direct-arc steel furnace, but the voltage used is very low and very large electrodes are

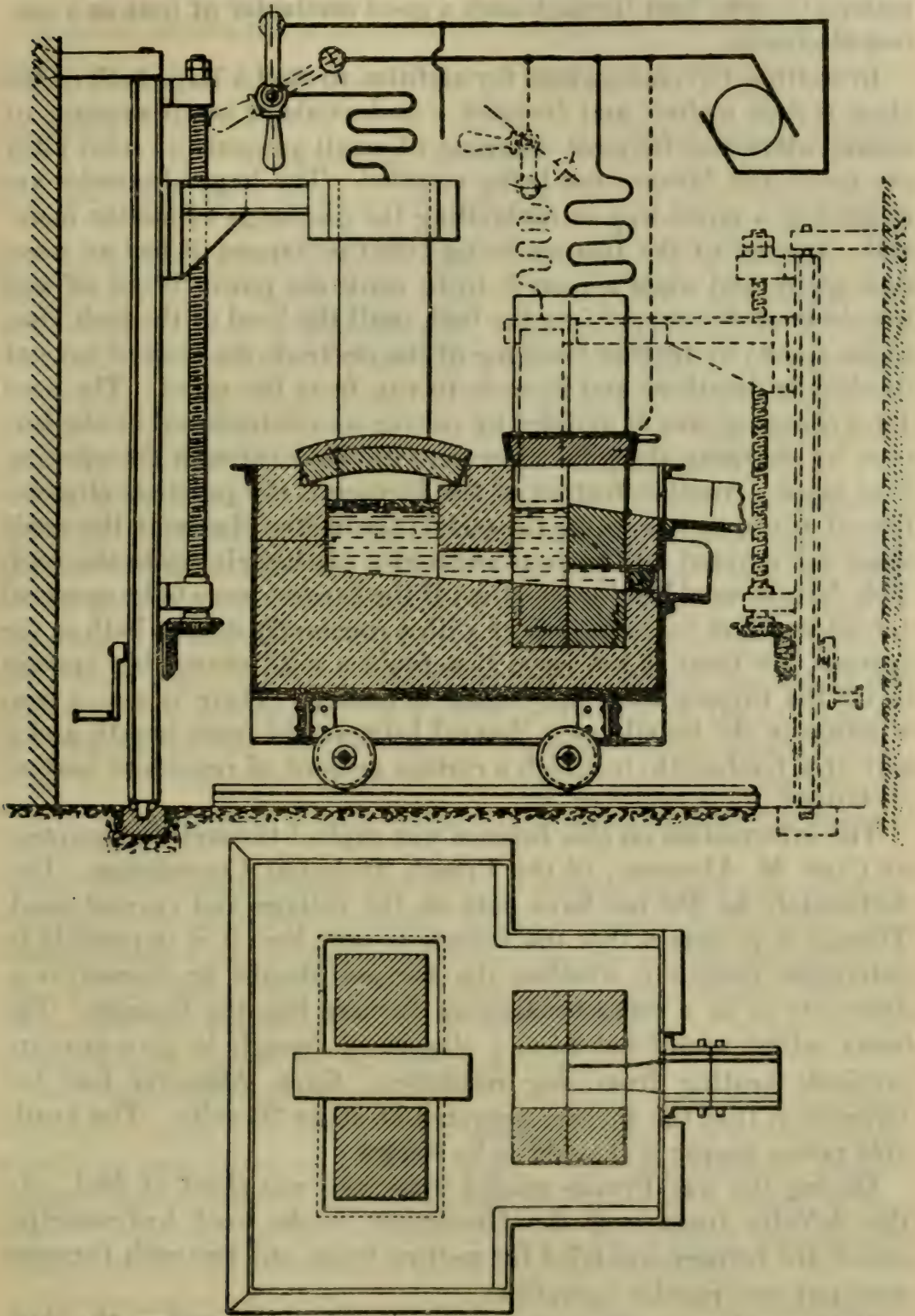


FIGURE 25.—Diagram of deNolly furnace.

used in order to distribute the heat generated and to help reduce local overheating. The carbon electrodes are so large (approximately 20 by

⁸⁶ deNolly, II., U. S. Patent 1,216,961, Feb. 20, 1917.

20 inches) that they almost eliminate any real roof to the furnace. This arrangement, though avoiding roof troubles, must involve a material loss of heat through such a good conductor of heat as a carbon electrode.

In melting ferromanganese for addition to steel a large bath of the alloy is kept molten, and frequent withdrawals of small amounts of molten alloy and frequent charging of small amounts of solid alloy are made, the furnace not being emptied. The huge electrodes are utilized in a novel way in controlling the discharge of molten material. Instead of the furnace being tilted or tapped it has an overflow spout, and when a pour is to be made the power is cut off and the electrode is lowered into the bath until the level of the melt rises to the spout; by further lowering of the electrode the desired amount of alloy is displaced and is made to run from the spout. The need for a charging door is avoided by raising an electrode out of the furnace by charging the solid alloy into the bath through the opening thus made. Another feature of the furnace is the practical elimination of any open space over the metal; the molten charge in the small space not covered by the huge electrodes reaches almost to the roof. This feature would be inconvenient if the furnace were to be operated for intermittent heats instead of with a constantly molten bath in the furnace, for there is not room to contain a solid charge big enough to fill the furnace after the charge is molten. There is also a constriction in the hearth, or a channel between the main hearth and a sort of a forehearth, in which a certain amount of resistance heating is claimed.

The information on this furnace was supplied through the courtesy of Capt. M. Altmeyer, of the French Technical Commission. Unfortunately he did not have data on the voltage and current used. Though it is certain that the voltage is very low, it is impossible to determine definitely whether the furnace should be classed as a direct-arc or as a contact-resistance furnace like the Bennett. The borax added would not form a slag thick enough to give any appreciable heating from slag resistance. Capt. Altmeyer had the impression that the furnace operated at about 30 volts. The available power supply is thought to be 300 kw.

During the war France needed brass and was short of fuel. As the deNolly furnace at the Grammont works used hydroelectric power, the furnace was tried for melting brass, and two such furnaces were put into regular operation.

Data on the operation of one furnace from December 19, 1916, at 8.25 a. m., to December 21, 8.52 a. m., are given in Table 41. To form a slag 35 to 40 kg. or 75 to 90 pounds of borax were charged with each heat. The charge was 60:40 brass scrap, with the addition of zinc to compensate for loss in melting. As a deoxidizer, 2 kg.

of aluminum per heat were added. The metal was poured direct into ingot molds placed on a turntable in front of the spout.

TABLE 41.—*French test of deNolly-Grammont furnace melting yellow brass.*

Heat No.	Date.	Time. ^a		Charge.		Zn.	Total.	Ingot poured.	Dross.	Power used.
		Charged.	Poured.	Turnings.	Crop ends.					
		<i>H. m.</i>	<i>H. m.</i>	<i>Kg.</i>	<i>Kg.</i>			<i>Kg.</i>	<i>Kg.</i>	<i>Kw. h.</i>
1.....	19.....	8 35	15 00	1,001	1,032	60	2,093	1,913	110	1,090
2.....	19.....	15 05	21 00	1,000	1,034	100	2,134	1,899	104	1,105
3.....	19-20.....	21 00	3 00	1,330	701	37	2,118	2,075	105	1,090
4.....	20.....	3 00	9 15	1,330	702	70	2,102	1,902	130	955
5.....	20.....	9 20	15 00	1,330	703	90	2,123	2,015	105	1,062
6.....	20.....	15 05	20 55	1,330	702	86	2,118	2,046	109	1,033
7.....	20.....	20 55	2 55	1,397	736	76	2,209	2,119	65	1,082
8.....	20-21.....	3 00	8 52	1,330	701	70	2,101	1,988	51	1,012
Total..	.....	.....	.....	.....	.....	589	16,998	15,957	779	8,429

^a Total time, 48 hours and 17 minutes. French time; same as 3 p. m.

The gross metal loss was 1,036 kg., or 6.1 per cent. No data are given as to whether the turnings contained oil or dirt or concerning the recoverable metal. If it be assumed that there was 2 per cent nonmetallic, oil and dirt, on the turnings and that 25 per cent of the dross was recoverable metal, the net loss would drop to about 4 per cent, a high figure, but not so high as to prevent the use of the furnace in the emergency. It will be noted that on the average $3\frac{1}{2}$ per cent excess zinc, on the basis of the total charge, was added to make up for volatilization losses, the charge being calculated for 58 per cent copper and 42 per cent zinc, in order to give the desired 60:40 brass.

The power consumption and rate of production are not good as compared to American practice, since a furnace taking 175 kw. average load, on 16,998 kg., about 37,480 pounds, or $18\frac{3}{4}$ tons, required 8.429 kw. h.; that is, 60:40 brass, doubtless poured at about 1,050° C., was melted on 24-hour operation, at the rate of 450 kw. h. per ton of metal charged, or 480 kw. h. per ton of metal cast.

The production was only some 780 pounds per hour with an average power input of 175 kw. The average charge was 4,650 pounds and the average time per heat six hours. The furnace seems underpowered for so large a charge, though doubtless an increase in the rate of power input, especially if obtained through an increase in voltage, would have resulted in increasing the loss of zinc.

The electrode consumption is given as 10 kg. of carbon electrodes per metric ton of brass, or 20 pounds per short ton. It is said that one man can operate one furnace, six other men helping during casting the ingots, or one man can operate two furnaces with a crew of 10 for aid in casting. With the heats coming out six hours apart it

would seem that by staggering the heats a crew able to handle the pouring of one furnace should suffice for two.

GRAMMONT MODIFICATION OF DENOLLY FURNACE.

Grammont⁸⁷ has patented a modification of the deNolly furnace which is evidently designed to make the design more suitable for work on copper and its alloys. Capt. Altmeyer stated that he thought M. Grammont's interest in the furnace concerned more the melting of copper than of brass.

The Grammont modification eliminates the forehearth and channel of the deNolly furnace, being a two-phase furnace with conducting bottom and two large, square carbon electrodes, which almost cover the hearth, as in the deNolly, and require very little refractory roof.

The furnace is rectangular, with charging doors at each end, the pouring spout being in the middle of a long side of the furnace. The overflow pouring scheme of the deNolly furnace seems to be retained. Above the conducting bottom, which rests on the lower metallic electrode built into the furnace, is a nonconducting hearth, with several (five shown in the patent) holes through it. The molten metal in these holes is in contact with the lower electrode and is supposed to be heated by its own resistance to a temperature higher than the body of the bath. This appears to be an attempt to combine heating below the bath in resistor tubes similar to the Hering "pinch-effect" furnace, with heating above the bath by a low-voltage arc or contact-resistance heating.

Now the Hering principle, as will be seen later in the description of the Hering furnace, requires such extremely high currents and low voltages that carrying these currents in carbon electrodes, even the huge ones of the deNolly-Grammont design, is impracticable because most of the heat developed would be in the electrodes, outside the furnace, rather than in the resistor holes or tubes. These holes in the hearth of the Grammont furnace therefore serve merely to make connection between the lower electrode and the bath and can not develop any appreciable proportion of the total energy developed in the furnace. The Grammont furnace must consequently be classed as a direct-arc or a contact-resistance furnace (the voltage to be used is not mentioned in Grammont's patent) rather than as a Hering type resistance furnace, and its power consumption and metal losses should not differ much from those of the deNolly furnace, although in construction (aside from the holes in the hearth) it is rather more simple than the deNolly. The holes in the hearth require either that the furnace be made to tilt (which is seemingly not contemplated), so that all molten metal could be drained from them if the furnace

⁸⁷ Grammont, E. French Patent 487,605, July 17, 1913.

were to be shut down, or else require that the furnace be kept hot continuously, so that the metal will not freeze in the holes and damage the hearth. Evidently the furnace would be simpler and more practical if the lower carbon electrode were extended up to the hearth instead of being connected to it by tubes full of molten metal.

It should be pointed out that for a given power input the low-voltage furnaces, whether they use direct-arc or contact-resistance heating, require high currents and consequently are subject to greater heat losses in leads and electrodes than are furnaces operating at higher voltages, so that the thermal efficiency of low-voltage furnaces tends to be lower than that of higher voltage furnaces using electrodes.

The question whether in these furnaces that structurally resemble direct-arc furnaces local superheating and consequent metal losses can be avoided by using very low voltages and utilizing contact resistance instead of a true arc or by using very large electrodes and attempting to spread the arc over a large surface instead of localizing it can not be answered by the available data. The big electrodes will not wear off smoothly to a perfectly flat, level tip, from which a short but very fat arc low in energy density—that is, generating few calories per unit of a very large area—can be drawn, but will wear off irregularly, with the result that the current will jump from the tiny projection nearest the charge, and thus the heating will be localized.

It is possible that by using a slag, like the borax used in the deNolly furnace, the electrodes might be slightly below the normal level of the slag and the slag be slightly blown away from it by the arc stream, for something of this nature is often noted in an ore-smelting furnace running at a low voltage. At a certain point there is no open, flaming arc, yet the slag does not wet the electrode even though the electrode is buried in it. Such a condition is usually called a submerged arc, and while such an arc is not as hot as a high-voltage open arc, its temperature is still certainly above the boiling point of zinc in brass. Moreover, this condition does not hold when the furnace contains a charge of solid metal at the beginning of a heat. Then the heating is essentially and necessarily localized, and though the metal may sometimes drip away from the arc as fast as melted and before it can be superheated, yet it must often collect in pockets and be held in the arc long enough to permit material losses of volatile constituents, unless the furnace is so tightly closed that the metal vapor can not escape. It would be difficult in the deNolly-Grammont furnace to make a vapor-tight joint between the huge carbon electrodes and the openings through which they enter and still provide for the necessary adjustment of the electrodes.

It is probable that a low-voltage direct-arc furnace might not have quite as high metal losses as the ordinary direct-arc furnace, and that the metal loss might be held low enough that, under some conditions, the simplicity of construction of the direct-arc type might make it pay to accept the metal loss, but under most American conditions it would seem that the chances were against such a furnace being useful. Until such a type of furnace has been shown to give much lower metal losses than those of the de Nolly test, or with that metal loss, to give materially better production, power consumption, etc., than other types of furnaces that show low metal losses, no form of direct-arc furnace should be used for melting alloys high in zinc. Whether a low-voltage direct-arc furnace would do good work on a red brass, bronze, leaded bearing metal, etc., is an open question, as only the high-voltage Snyder has been used for them.

VON SCHLEGELL-FLETCHER FURNACE.

A suggestion for minimizing the metal loss in a direct-arc brass furnace is found in the von Schlegell-Fletcher patent,⁸⁸ whereby the brass is to be melted down by a direct arc, and after it is melted an extra electrode is stuck in through the pouring spout and the heating is continued by an indirect arc, that is, one between carbon or graphite electrodes above the melt.

To reduce further the surface overheating that occurs even with an indirect arc, the hearth of this furnace is made deep and of small cross section in order to present as little surface as possible to the direct heat from the arc over it. As heated metal stays at the top, this deep hearth will defeat its own purpose; to get the metal in the bottom of the hearth hot enough to pour, the surface layer must be even more violently overheated than it would be with a wide and shallow hearth, so that the scheme would invite rather than prevent metal losses. The deep hearth also offers every opportunity for the composition of the melt to vary between the first and the last metal poured, owing to separation of heavy constituents by gravity. So far as is known this furnace has not been tried or constructed.

DIRECT-ARC FURNACES IN WHICH THE ARCS ARE IN MOTION.

VON SCHATZL FURNACE.

Von Schatzl⁸⁹ designed a furnace consisting of a large upright hoop-shaped trough mounted to rotate like a wheel on a jacked-up axle. The electrodes are set at a slight angle so that their tips enter the trough at the lower part of the hoop; the arcs drawn from the

⁸⁸ Von Schlegell, F., and Fletcher, C. R., U. S. Patent 1,294,837, Feb. 18, 1919.

⁸⁹ Von Schatzl, G., German Patent 231,734, Feb. 28, 1911; von Schatzl, G., and Krieger, E., Austrian Patent 49,448, Aug. 25, 1911.

electrode to the charge heat the latter, which lies below the electrodes in a small sector of the trough. The rotation of the hoop is designed to mix the charge and to promote homogeneity. Among the possible uses is mentioned the melting of steel. It is not known whether this furnace has been actually constructed or not.

BUCKMAN FURNACE.

Buckman⁹⁰ describes a direct-arc furnace in which the electrodes are eccentrically located and rotate, thus distributing the heat and reducing its localization. The mechanical details as to the making of electrical connection for these moving electrodes are not given. The furnace has not been specifically suggested for brass, nor is any embodiment of the scheme in an actual furnace known to have been made.

SUMMARY IN REGARD TO DIRECT-ARC FURNACES.

Direct-arc furnaces superheat the surface of the charge so that if the charge contains much zinc, lead, or other volatile metals, the metal losses are very great. Furnaces built like direct-arc furnaces but using so low a voltage that no true arc is formed are possibilities concerning which too little is known to make them available for present general use. Direct-arc furnaces could be used on pure copper (if the problem of copper poisoning by fumes is solved), on true bronze, aluminum bronze, or red brass not too high in zinc or lead, but can not be satisfactorily used, even for occasional heats, on yellow brass. Only one commercial application of true direct-arc furnaces to copper alloys is being made in the United States at present.

This type of furnace is the accepted standard for steel and nickel-chromium alloys and works well on Monel metal. It might work on aluminum or aluminum-copper alloys, but no actual trials have been recorded. Aluminum is so prone to absorb gases at high temperatures that the direct arc might not produce a good quality of metal.

STATIONARY INDIRECT-ARC FURNACES.

MOLDENKE FURNACE.

Indirect-arc furnaces do not superheat the surface of the melt so severely as direct-arc furnaces, and the indirect-arc type therefore, has a wider application to brass and bronze.

Perhaps the earliest suggestion of the use of an indirect-arc furnace for brass, though the main object was melting steel, was that of Moldenke,⁹¹ in 1896. The charge was to be placed on an inclined sur-

⁹⁰ Buckman, H. H., U. S. Patent 1,092,764, Apr. 7, 1914.

⁹¹ Moldenke, R. G. J., U. S. Patent 569,221, Oct. 13, 1896.

face, preheated by heat transmitted to this inclined surface by a fuel-fired furnace, melted by the heat radiated from one or more arcs, and then allowed to run into a sump, where it was to be heated to pouring temperature, and from which it was to be tapped. Since this suggestion was made before the first Stassano patent (1898) or the first Heroult patent (1900) at a time when electric-furnace design was in an embryonic state, it is not remarkable that the idea was not carried to fruition. It is more than possible that the principle of preheating the charge by fuel and of finishing the melt by electric heat may be found desirable, though such a development is still in the future.

CONTARDO FURNACE.

In 1901 Contardo⁹² described a tilting indirect-arc furnace more nearly approaching modern furnaces in the relative size and arrangement of parts.

HANSEN'S TEST OF WEEKS'S ZINC FURNACE ON COPPER.

Hansen made a heat or so of pure copper in the Weeks indirect-arc zinc-smelting furnace, the furnace being stationary, and has described the furnace and given data on the test.⁹³

The furnace had the form of a horizontal cylinder with electrodes entering each end through stationary heads, which did not move when the furnace was melted to pour. Starting with a cold furnace, 2,000 pounds of copper ingots were melted with 630 kw. h. in 3 hours and 50 minutes, and 1,926 pounds of copper were recovered, giving a gross loss of 3.7 per cent, part of which was doubtless due to soak-ages into the fresh lining. From this test Hansen calculates that an indirect-arc furnace should melt brass at less than 300 kw. h. per ton. Having made no tests on brass in the Weeks furnace, he does not commit himself very definitely as to metal losses.

Weeks⁹⁴ has discussed the possible application of his zinc furnace to brass, but the discussion is not based on actual test.

SHIPTON FURNACE.

Shipton⁹⁵ has suggested a modification of the ordinary indirect-arc type especially intended for brass melting. In the Shipton furnace the metal is charged, for preheating, on a tiltable refractory shelf located above the arcs, but below the roof. After the metal is preheated it is dumped into the melting chamber proper by tilting the shelf. This is an attempt to utilize, more directly than merely

⁹²Contardo, E. C., U. S. Patent 688,597, Dec. 10, 1901.

⁹³Hansen, C. A., Electric melting of copper and brass: Trans. Am. Inst. Metals, vol. 6, 1912, p. 119.

⁹⁴Weeks, C. A., Melting nonferrous metals in an electric furnace: Met. and Chem. Eng., vol. 6, 1911, p. 502.

⁹⁵Shipton, J. D., U. S. Patent 1,312,746, Aug. 19, 1919.

by reflecting it back from the roof, the heat radiated upward from the arcs. Such a construction, however, violates the principle that no complications are permissible in the hot interior of a furnace.

The patent leaves to the imagination the selection of a material suitable for the construction of this movable shelf.

The upkeep and repair of such a part of the furnace would necessarily be so expensive, difficult, and troublesome, as to nullify any advantage that might accrue from more directly utilizing the heat radiated upward from the arcs. It is unlikely that this furnace has ever been operated.

INDIANAPOLIS FURNACE.

Late in 1915 an indirect-arc furnace operated in a stationary position, but tilted to pour, was advertised by the Indianapolis Electro Metals Co. for melting brass. This furnace was single-phase, built in the form of a horizontal cylinder, with electrodes entering at each end, but the electrodes tilted with the furnace, thus avoiding the joint between electrode support and furnace body that was a weak point in the design of the Weeks' zinc furnace. Certain claims were made as to the performance of this furnace, and photographs of the furnace, which had a capacity of perhaps 500 pounds, taken during the pouring of a heat of copper, were sent in.

The data and photographs were lost in the fire that destroyed the Bureau of Mines office at Cornell University in 1916. Letters addressed to the firm thereafter were returned undelivered, so the data and photographs could not be replaced. The furnace was never in commercial use.

STASSANO-TYPE FURNACE TESTED BY HANSEN.

The first indirect-arc furnaces to attain any real commercial use were those designed by Stassano, so indirect-arc furnaces are often referred to as being of the Stassano type, just as direct-arc furnaces are referred to as being of the Heroult type, because Heroult was the first to make commercial furnaces of that type. Siemens⁹⁶ had invented and described both types long before, but as the term "Siemens furnace" does not tell which type is meant the terms "Heroult" and "Stassano" are often loosely used as a convenient shorthand to designate the direct-arc and the indirect-arc type of furnaces.

In 1913-1914 Hansen, instead of continuing with the Weeks furnace, designed a Stassano-type furnace at the Schenectady works of the General Electric Co. for melting brass. This furnace was three-phase, holding 3,500 to 4,000 pounds, and was operated without the

⁹⁶ Siemens, W., English Patents 4,208 of 1878 and 2,110 of 1879.

oscillating motion of the Stassano. When it was tried on yellow brass borings the surface overheating of the charge was so great that the furnace could not be kept closed, clouds of zinc vapor escaped, the metal losses were high; the product analyzed 27 per cent zinc when the borings charged contained 33 per cent, and the furnace was evidently not suitable for yellow brass. The furnace was later used for other purposes and no detailed records of its operation on brass are available.

The Scoville Manufacturing Co. also tested a Stassano-type furnace on yellow brass and encountered such difficulties from superheating of the surface, from excessive zinc loss, sticking of the electrodes, and attack of the electrode coolers, due to condensation of zinc, that they abandoned it.

According to Cone⁹⁷ there was in January, 1920, only one Stassano furnace—that one being used for steel—in the United States. In Italy, however, a large part of the steel furnaces are of the Stassano type, as according to recent figures⁹⁸ there are 40 Bassanese, 26 Stassano, and 22 Angelini furnaces, or 88 indirect-arc-type furnaces, to 14 Heroult and 10 Keller, or 24 of the direct-arc type. The Bassanese⁹⁹ and Angelini furnaces are Stassano-type furnaces said to be made by former employees of Stassano.

Figure 26 shows the principle of a single-phase Stassano-type furnace, and figure 27 the plan of a three-phase Stassano steel furnace.

STASSANO-PETINOT FURNACE.

Schmelz¹ describes Petinot's² modification of the Stassano furnace, which mainly consists in making the roof so thin that enough heat is lost to keep the roof fairly cool and hence increase its life. This furnace was tested at the plant of the Titanium Alloy Manufacturing Co., but the only information given on the test is that 1,000 pounds of copper was melted in a 120-kw. furnace in less than two hours. No tests are cited on brass and no metal losses given.

BUREAU OF MINES TESTS ON SMALL STASSANO-TYPE FURNACE.

In order to get an idea of the metal losses in an indirect-arc furnace the Bureau of Mines made a few tests, starting in March, 1913, in a small furnace built in a 100-pound Schwartz open-flame oil-furnace shell, loaned through the kindness of the Hawley Down-

⁹⁷ Cone, E. F., The status of the electric steel industry: *Iron Age*, vol. 105, 1920, p. 75.

⁹⁸ T. D., 1,000 fours électriques à arcier dans le monde: *Jour. du four électrique*, vol. 28, 1918, p. 114.

⁹⁹ Bassanese, F., English patent 1,173 of 1915; see also Hvidsten, T. M., and Ingelsrud, A. H., U. S. Patent 1,222,007, Nov. 16, 1916.

¹ Bassanese, F., and Pettinot, N., U. S. Patent 1,093,494, Apr. 14, 1914.

² Schmelz, E. M., Electric furnace for medium temperature: *Trans. Am. Inst. Metals*, vol. 8, 1914, p. 261.

Draft Furnace Co. Two graphite electrodes at an angle of about 120° entered through holes cut in the shell; they were protected by water coolers outside the shell and were adjusted by a crude device. The regular fire-brick lining was first coated with a layer of asbestos cement and later with a mixture of magnesite and alundum cement. The furnace was run at about 35 kw. On eight heats of about 100 pounds each of yellow brass ingot, about 30 per cent zinc, poured at an average of $1,050^\circ\text{C}$. ($1,925^\circ\text{F}$.) the following results were ob-

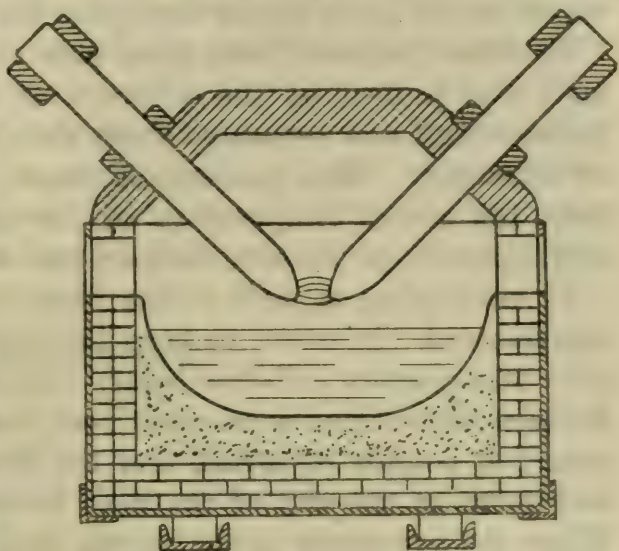


FIGURE 26.—Diagram showing principle of single-phase Stassano-type furnace.

tained: 804.5 pounds were charged; $775\frac{1}{4}$ pounds ingot and $6\frac{3}{4}$ pounds spillings and shot reclaimed from slag were obtained—782 pounds total, a net loss of $22\frac{1}{2}$ pounds, or 2.8 per cent.

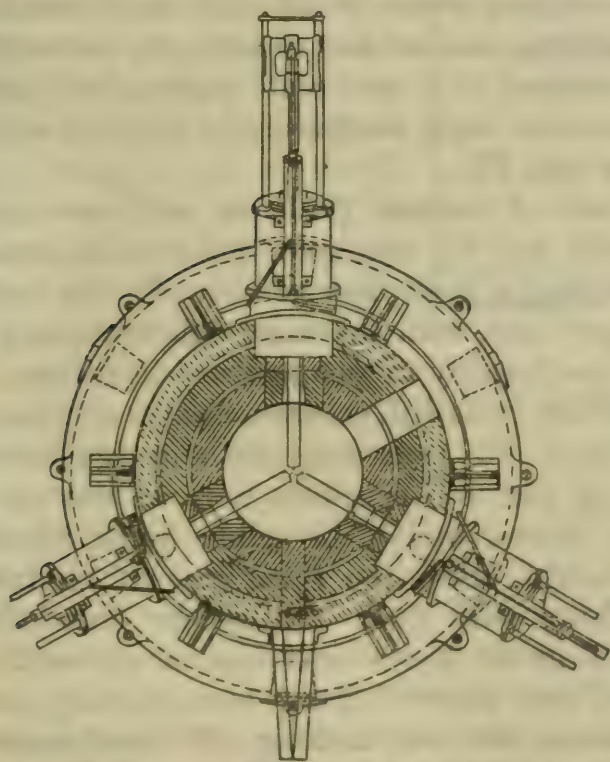


FIGURE 27.—Plan of three-phase Stassano steel furnace.

In seven heats of an alloy of about 78 per cent copper, 18 per cent zinc, and 4 per cent lead, poured at about $1,100^\circ\text{C}$. ($2,000^\circ\text{F}$.), 686 pounds ingot were charged, $655\frac{1}{2}$ pounds ingot poured, and 14 pounds metal recovered from spillings and slag—total $669\frac{1}{2}$ pounds, a net loss of $16\frac{1}{2}$ pounds, or 2.4 per cent. The use of salt, glass, etc., for a slag seemed to have no measurable effect in reducing the loss.

The furnace was kept tightly closed while running, and, although metallic zinc condensed about the electrodes, in the furnace walls, and in the pouring spout, no fume escaped, save that sometimes toward the end of a run the pressure of zinc vapor became strong

enough to blow out the luting about the spout plug. At such times or when the spout was opened to pour, a hissing stream of zinc vapor would shoot out of the spout for several feet.

In order to avoid loss from this cause, the temperature of the melt was judged by the readings of a pyrometer situated in the furnace wall and separated from the charge by about one-half inch of refractory. This reading, of course, showed a temperature lower than the actual temperature of the metal, and only approximate extrapolation to the true temperature was possible.

In attempting to melt yellow brass borings many difficulties were encountered. In order to keep the borings well away from the arc only 56.6 pounds (oil-free basis) were charged in one heat into the furnace warm from a previous heat, though the furnace would hold over 100 pounds of metal, and the furnace was tilted slowly back and forth at the end of the heat in the hope of stirring the melt. When the pyrometer in the hearth read 900°C ., which corresponded to about $1,040^{\circ}\text{C}$. in the metal itself, the furnace was opened. Though the bottom of the melt was hardly hot enough to pour, the top was boiling violently, and on it was much fine, powdery dross. Only 46.25 pounds of ingot were obtained, or about 18 per cent gross loss; 5.5 pounds of dross containing about 90 per cent, or 5 pounds, metallics were recovered, bringing the net loss down to $9\frac{1}{2}$ per cent.

The original borings contained 61.4 per cent copper, 34.9 per cent Zn., 3.7 per cent Pb., and the ingot analyzed 68.5 per cent copper, 28.2 per cent Zn., 3.3 per cent Pb.

Another heat of 100 pounds of borings (97.5 per cent metallic, oil-free basis) with $3\frac{1}{2}$ pounds salt for slag gave $80\frac{1}{2}$ pounds ingot and $11\frac{1}{2}$ pounds metal from slag, a gross loss of about 18 per cent and a net loss of nearly 6 per cent, with the same difficulties as to surface overheating and nonuniformity of temperature as before.

As no watt-hour meter had been installed, accurate figures of power consumption were not obtained. No runs were made on red brass because in 1913 the prices of fuel and crucibles were so low that the field of electric furnace seemed limited to yellow brass, where reduction of metal losses might bring the total cost of electric melting below that of melting with fuel. On yellow brass the indirect-arc furnace showed metal losses equaling or exceeding those of fuel-fired furnaces, and hence did not seem suitable, at least without vital modifications, for such melting. Without modification the local superheating of the surface of the metal, directly beneath the arc, made the indirect-arc furnace of little use for melting alloys high in zinc, although the superheating and the melting losses on the same class of material were not quite as bad as in the direct-arc type. It was realized that if an indirect-arc furnace were greatly underpowered, so that the rate at which heat was

generated by the arc was very low, the thermal conductivity of the charge might more nearly keep pace with the generation of heat, and surface overheating might be minimized. But such an underpowered furnace would be thermally inefficient, its power consumption per ton of metal melted would be high, and its rate of production low, so that its use, even if the excessive metal loss could be thus prevented, would not be economical. The use of a number of very small arcs instead of one large one, in order to distribute the source of heat, is possible, but tends to complicate the furnace and to increase its cost.

RENNERFELT FURNACE.

Only one stationary indirect-arc furnace, the Rennerfelt,³ has found commercial application to nonferrous metals.

According to Cone,⁴ out of 148 Rennerfelt furnaces in operation in the world in January, 1920, 32 were melting nonferrous alloys, 8 of these being in the United States and Canada.

The Rennerfelt furnace differs but slightly in principle from the Stassano furnace, the main difference lying in the shape of the arc. The Stassano is normally a three-phase furnace, using three electrodes placed 120° apart and at an angle of some 15° to 45° from the horizontal, the three electrodes thus pointing toward the center of the furnace, but inclining slightly downward. The arc then plays from any one electrode to the other two, forming a sort of Y lying on its side, as shown in figure 28.

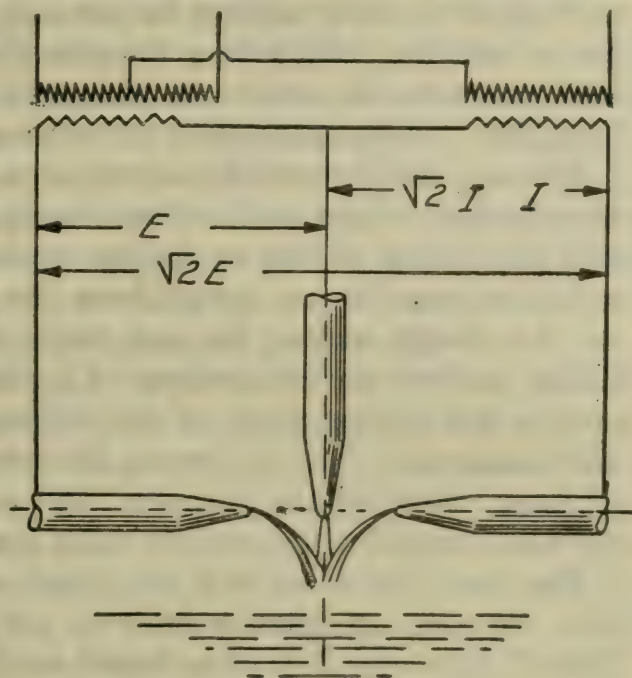


FIGURE 28.—Arrangement of connections to electrodes of Rennerfelt furnace.

The Rennerfelt is essentially a two-phase three-wire furnace, the two-phase current being taken from a three-phase line by the Scott connection. One electrode is vertical and serves as a common return for both phases. The other two electrodes are horizontal (or in some of the furnaces are movable in a vertical plane so that they may be

³ Rennerfelt, I., U. S. Patent 1,076,518, Oct. 21, 1913; Herlenius, J., U. S. Patent 1,338,631, Apr. 27, 1920. For a modification see Groeger, L. C. H., U. S. Patent 1,333,914, Mar. 16, 1920.

⁴ Cone, E. F., The status of the electric steel industry: *Iron Age*, vol. 105, 1920, p. 75.

at an angle of some 15° above or below the horizontal). The arc plays from each horizontal electrode to the vertical electrode, but the mutual repulsion of the current in the various electrodes throws the arc downward so that it has, roughly, the form of a fleur-de-lis. Thus the shadow of the vertical electrode protects the center of the roof from the direct radiation of the arc, whereas in the Stassano the roof is open to this radiation. Therefore the roof in the Rennerfelt, other things being equal, lasts longer than that in the Stassano. Although the Rennerfelt is a much newer furnace than the Stassano, it has been used much more in this country for steel melting, although for this purpose it is used much less than direct-arc furnaces. In recent Rennerfelt steel furnaces the side electrodes are capable of being tilted so far downward from the horizontal that, if desired, the furnace may be operated with a "free burning" arc—that is, as an indirect-arc furnace—while the cold charge is melting down, thus making the arc stable at the time when a direct arc is unstable. By tilting the side electrodes downward the arcs may thereafter be drawn to the surface of the bath, the furnace being thus finally operated as a direct-arc furnace.

Running the Rennerfelt on brass in this way would result in worse superheating of the surface than running as an indirect-arc furnace, and the tilting of the electrodes would preferably be upward in order to keep the arc away from the top of a new cold charge. As the charge melted the arc might be lowered. However, this tilting involves the maintenance of a refractory ball-and-socket joint or else the cutting away of the refractory about the electrode to allow clearance, thus weakening the furnace and increasing the loss of heat. Most of the furnaces used on nonferrous alloys do not have this complication, and its value for such use is questionable.

The early furnaces had the form of horizontal cylinders, but later furnaces are usually built as upright cylinders, as shown in Plate XII, A (p. 204), the domed roof being removable for easier maintenance.

The Rennerfelt furnace was described by vom Baur,⁵ who claimed power-consumption figures of 168 kw. h. per metric ton (153 per short ton) on red brass and 197 per metric ton (179 per short ton) on copper and less than 160 per short ton on leaded bearing metal. These figures were obtained in a steel furnace hot from a melt of steel, and much melting was done by stored heat, so that the figures were unduly optimistic and have not been attained in regular operation, as might be expected from their representing about 100 per cent of the theoretical efficiency.

⁵ vom Baur, C. H., The Rennerfelt electric arc furnace: Trans. Am. Electrochem. Soc., vol. 25, 1915, p. 877; Rennerfelt electric furnace operation: Trans. Am. Electrochem. Soc., vol. 25, 1917, p. 87.

SWEDISH DATA ON THE RENNERFELT FURNACE.

The first account of the operation of the Rennerfelt furnaces on brass was given in 1914,⁶ when it was stated that in a hot 60-kw. furnace 209 pounds copper were melted in 30 minutes at the rate of 290 kw. h. per ton and 164 pounds of 60:40 brass (from copper and zinc) in 20 minutes at the rate of 244 kw. h. per ton. According to this account the brass was of excellent quality and there was practically no loss from oxidation. As this report suggested that the furnace was applicable to yellow brass, inquiry was at once made for further details. The reply said that the copper was first melted, and the zinc then added and heated for seven minutes, and that "very little zinc oxide was noticed flying around the furnace." The charge was 44.5 kg. copper and 30 kg. zinc. The alloy obtained analyzed 38.1 per cent zinc. On the assumption that there was no loss of copper, the zinc in the alloy amounted to 27.4 kg. and the total weight of alloy was 71.9 kg., a loss of 2.6 kg., or 3.5 per cent.

In 1916 some further information was obtained on the operation of a 50-kw., 600-pound furnace at the Nordiska Armatur Co. in Sweden. The power consumption (with furnace hot, that is, 24-hour basis) on 60:40 brass made from copper and zinc was about 225 kw. h. per short ton. The metal loss ran from 6 per cent to 4 per cent on 60:40 brass, according to the nature of the charge. On red brass melted by the Atvibaberg Co. the average power consumption was 365 kw. h. per ton and the metal loss under 1.5 per cent.

In a similar furnace running at about 65 kw., at the Svenska Metallverken, the power required to melt copper, with the furnace fully hot at the start, was 220 kw. h. per ton, but if the metal had to be superheated (temperature not given) it took 340 kw. h. per ton. The gross metal loss on scrap copper was under 1 per cent and corresponded with the amount of nonmetallic present, the true metal loss being practically zero. In a 1,200-pound furnace on a run of 254 tons the average power consumption on pure copper was 365 kw. h. per ton, but this probably refers to 24-hour operation. The metal loss was 0.86 per cent, no deduction being made for dirt on the charge, which was mainly old scrap. The electrode consumption with carbon electrodes was 10 pounds per ton, but it is stated that this would be halved with graphite electrodes.

The furnace was reported to melt copper, bronze, and red brass much better than yellow brass, the zinc fumes condensing on the electrodes in melting yellow metal and care being required in cleaning the electrodes from time to time.

As experience was gained with the furnace its agents saw that it was not applicable, under American conditions, to alloys high in zinc,

⁶ Anonymous, A small-sized electric-arc furnace: Met. and Chem. Eng., vol. 12, 1914, p. 275.

and in their advertising literature carefully point out that attempts to melt alloys with much more than 20 per cent zinc are not desirable.

Johnson¹ has shown that at the normal pouring temperatures the pressure of zinc vapor for the various brasses is as follows:

TABLE 42. *Partial pressures of zinc vapor for different brasses.*

Alloy:	Partial pressure of zinc.
Cu 60, Zn 40	atmospheres__ 0.78
Cu 65, Zn 35	do_____ .71
Cu 70, Zn 30	do_____ .66
Cu 80, Zn 20	do_____ .33

On account of the high volatility, at pouring temperature, of zinc in the alloys rich in zinc it is obvious that not much local overheating of the surface will be needed to cause a large loss of zinc, and that there is more leeway on the 80:20 alloy. Commercial practice with the Rennerfelt agrees with the theory. As a matter of fact, even on a 20 per cent zinc alloy the loss in an indirect-arc furnace is higher than in other types of furnaces that are freer from surface overheating, and the operation of the indirect arc furnace is troublesome.

Notwithstanding the metal loss, the furnace has been used in Sweden on alloys high in zinc. The data on a test made in June, 1919, follow:

MELTING YELLOW BRASS IN A LOW-POWERED RENNERFELT.

The furnace was of about 3,000 pounds capacity, operated at about 100 volts, and had a 225-kv. a. transformer. The power input was, however, held down to about 110 kw. (93 to 127) in order to avoid surface overheating as much as possible. After a heat was poured the charge of scrap with 42 to 45 per cent zinc was charged, pouring and charging taking about an hour. The furnace was fully hot at the beginning of the test, and was operated 23 hours a day, not being run from midnight to 1 a. m.

Eight heats of 2,860 pounds (2,750 pounds scrap plus 110 pounds zinc added at the end of the heat), or 11.44 tons, were melted in 38 hours elapsed time, less two midnight periods, or 36 hours, 3,478 kw. h. being used, or 304 kw. h. per ton. The rate of production was only 635 pounds per running hour, leaving out the idle hour at midnight. The electrode consumption was 4 $\frac{3}{4}$ pounds per ton of metal melted; 5-inch diameter jointed carbon electrodes with graphite nipples were used. The power factor was about 85. Cast iron instead of copper or brass water coolers were used about the electrodes, as the volatilized zinc deposits on the nonferrous coolers and attacks them.

¹Johnson, J. The volatility of the constituents of brass: Jour. Am. Inst. Metals, vol. 12, 1919, p. 35.

The net metal losses are given as $2\frac{1}{2}$ to 3 per cent on the metallic basis, oil and dirt on the charges being allowed for. To 2,750 pounds of scrap 110 pounds of zinc, or 4 per cent of the weight of the scrap, are added to compensate for the volatilization loss and maintain the composition.

Such a loss is greater than that in good fuel-fired crucible practice in American rolling mills. Under Swedish conditions, however, melting yellow brass in the Rennerfelt is cheaper than in fuel-fired furnaces, even at the low power input used, which gives a low rate of production and a high power consumption, considering that the furnace was large, the melting point of the alloy low, and the furnace was operated 23 hours a day. Probably the prices of zinc and of crucibles do not differ greatly in Sweden and in the United States; but at the time of this test coal was costing \$50 to \$75 per ton in Sweden and coke was correspondingly high, whereas electric power could be had at 1 cent or less per kw. h. Melting with coke therefore cost so much more for fuel than melting with electricity—say \$15 to \$20 per ton of brass for coke melting against \$3 per ton for electric melting—that the loss of even 3 per cent more zinc or 60 pounds per ton, at, say, 10 cents per pound, or \$6, was far more than made up by the \$12 to \$17 lower cost of power than of coke, plus the saving through elimination of crucibles.

Under American conditions melting 60:40 brass in a stationary indirect-arc furnace would be decidedly uneconomical. A firm normally melting red brass in such a furnace could, of course, make an occasional heat on an alloy high in zinc, at the cost of some extra metal loss, by reducing the normal rate of power input and thus lessening surface overheating. If, however, the plant were to produce any notable proportion of alloys high in zinc, a type of furnace giving better results on such alloys should be chosen.

DATA ON A 100-KW. RENNERFELT FURNACE AT GERLINE BRASS FOUNDRY.

Through the courtesy of the Gerline Brass Foundry Co. a representative of the Bureau of Mines was allowed to watch the 100-kw. Rennerfelt furnace in operation at that company's plant and was given full data on the first 117 heats made with it in 1917, though metal loss determinations had been made on some 50 heats only.

The arcs normally operate at about 100 volts, but by throwing switches another transformer tap can be used, giving 70 volts. Each phase contains a two-coil reactance, and by switches all, half, or none of the reactors may be used. If the arcs are snappy when starting up from the cold, all the reactance is thrown in; with the furnace at full temperature and the arcs stable it is all cut out. The power factor varies from 75 to 85.

The furnace shell is about $4\frac{1}{2}$ by $4\frac{1}{2}$ by 4 feet high, and the furnace tilts on large hollow trunnions, through which the side electrodes, which are not capable of vertical adjustment, enter the furnace body. The electrodes are graphite, the side ones being 2 inches in diameter, and the top one, which is the common return for both phases and hence carries more current than the side ones, being 3 inches in diameter. The side electrodes carry about 600 amperes each, in normal operation. By means of rods and gears the side and top electrodes are all regulated by handwheels at the back of the furnace, from which position the switchboard and meters can be seen. The electrodes pass through water coolers, but the electrode holders themselves are not water cooled. The electrode control does not allow the electrodes to be drawn completely out of the way while charging, but the electrode holders have to be unscrewed to allow the electrodes to be pulled back out of the way, as is regularly done when charging.

The furnace holds about 650 pounds of metal. The bottom of the hearth is 10 $\frac{1}{2}$ inches below the horizontal electrodes. As the arcs are deflected downward, the tip of the arc flame comes rather close to the surface of the charge. The shell is lined, first with 1 inch of asbestos, within which is a $4\frac{1}{2}$ -inch layer of Woodland fire brick, and within this a $2\frac{1}{2}$ -inch layer of silica brick on the sides, which is covered by the rammed-up material, ganister plus a cement of fine silica sand bonded with linseed oil and water glass, that also forms the bottom. The arched roof is made up of a $4\frac{1}{2}$ -inch layer of clay-bonded carborundum brick, covered by $4\frac{1}{2}$ inches of fire brick. The center of the roof is not lagged above the fire brick, but the edges are covered with infusorial earth brick and cement.

A 15 by 15 inch charging opening is covered by a sliding door of fire brick in an iron frame, which is wedged up to tighten it. The pouring spout in the bottom of the charging opening is closed by a fire-brick plug. The furnace is kept as tightly closed while running as possible.

This furnace is used on jobbing work and it has seldom been necessary to force the furnace to its maximum production. Often the furnace has had to be held back while waiting for molds to be put up, and smaller charges than those on which it would show maximum efficiency have often been used. It has been operated only on one shift a day, usually about 10 hours, never on a 24-hour basis. The output has been normally from 1,500 to 2,500 pounds a day.

The first 117 heats averaged not far from 550 pounds each, or about $\frac{1}{2}$ ton, and the total power used for them, including all pre-heating of the empty furnace, was 18,156 kw. h., or about 575 kw. h. per ton.

From the results obtained in regular practice, without pushing the furnace to its limit, it seems that if pushed the furnace can melt

on 10-hour operation about 3,500 pounds of red brass at about 475 kw. h. per ton. Though so small a furnace would probably not be used for 24-hour operation, it should give, if operated 24 hours a day, with no unnecessary delays, nearly 5 tons a day at about 380 kw. h. per ton. The electrode consumption, exclusive of breakage, was about $3\frac{1}{2}$ pounds per ton. Very few electrodes were broken when operating on red brass, but the breakage was high when melting an alloy of 20 per cent zinc. The carborundum roof appeared good for more work after 400 heats.

The furnace has been used on a few heats of Monel metal, turning out 500 pounds in four hours, at the rate of about 1,200 kw. h. per ton, and as there are no volatile metals in Monel metal the loss ranged from zero to one-tenth of 1 per cent. Very good Monel castings were made from metal melted in the furnace.

Pure copper has been melted in the furnace, starting hot, at the rate of 500 kw. h. per ton and with a loss of two-tenths of 1 per cent. On 16 heats of red brass, made from scraps, gates, ingot, and new metals, in which 8,669 pounds were melted, 8,469 pounds ingot or castings were recovered, giving a gross loss of 2.3 per cent, no deduction being made for metal recoverable from slag or for spillings. In the coke fires the gross loss on this material was said to be about 4 per cent.

On 26 heats of "half-yellow half-red"—that is, an alloy made up of half-red scrap, ingots, or gates and half-yellow ingots, the mixture containing 20 to 22 per cent zinc—13,689 pounds were melted and 13,347 $\frac{1}{2}$ pounds were obtained, giving a gross loss of 342 $\frac{1}{2}$, or 2.46 per cent. The gross loss in melting this material in coke fires was given as 4.5 per cent. On three heats from 1,700 pounds of all borings (20 per cent zinc) 1,621 pounds were obtained, a gross loss of 79 pounds, or 4.6 per cent. On two heats from 1,191 pounds of all-yellow ingot (about 36 to 40 per cent zinc) 1,071 pounds were obtained, the furnace being run at a low power input to reduce local overheating, a gross loss of 48 pounds, or 4 per cent. The loss on this in coke fires is given as 3.5 per cent.

On one heat of all-yellow borings 308 pounds were charged. The furnace could not be held tight, though the power input was kept down to 60 kw., and a flame 3 feet long shot from the furnace throughout the latter part of the heat. Only 153 pounds ingot could be poured from this heat, the rest of the metal being volatilized or coming out as powdery dross.

Even on the 20 per cent zinc alloy, melting half-red scrap and half-yellow ingots, there was much trouble from zinc vaporizing, condensing on the electrodes and making them stick in the furnace walls or water coolers, so that they could not be adjusted. In taking them out to clean them from the zinc deposit much time was lost, and in

18 consecutive heats on the 20 per cent zinc alloy nine electrodes were broken. The Gerline Co. states that the furnace does wonderful work on Monel metal, excellent work on copper and red brass, works satisfactorily, all things considered, on the 20 per cent zinc alloy, but the company would not recommend it "under any circumstances or to anyone" for yellow brass. On one heat of an alloy high in lead the last few castings from the last ladle were said to be nearly pure lead, but it was also stated that this trouble could be largely overcome by careful stirring. In general, the quality of the metal is just as good as that from pit fires, and on account of the high prices of crucibles in 1917 the Gerline Co. was of the opinion that the melting cost was decidedly low. Although this furnace was very satisfactory, it has not been operated recently because the central station supplying power has been too heavily loaded to carry even this small furnace.

OTHER RENNERFELT FURNACES IN USE.

A Rennerfelt furnace of one of the older types of about 600 to 800 capacity, 90 kw., was installed by Titanium Bronze Co. a couple of years ago, but its installation was delayed. The furnace was said to be not well arranged mechanically and melting practice at this plant became established in oil; the electric furnace was used only on a few trial heats and never thoroughly tested. Another Rennerfelt of 1,000 pounds capacity, as well as a Snyder of similar capacity, are installed at the laboratory of the Chile Exploration Co., New York City, but both are used for purely laboratory purposes on many materials, not for regular production.

Small Rennerfelts are also installed for laboratory or test purposes only at the Driver-Harris Co., Haynes Stellite Co., and General Chemical Co. The Haynes Stellite Co. says that its furnace is not considered very satisfactory.

A small Rennerfelt was in use at the Acieral Co.'s plant for making "hardeners" for use in aluminum alloys before that plant was closed, and that furnace has been installed for a similar purpose at the Bausch Machine Tool Co., Springfield, Mass.

A 1,000-pound Rennerfelt has been installed by the Hardite Metals Co., Long Island City, N. Y., for use on nickel-chromium alloys.⁸

PERFORMANCE OF RENNERFELT FURNACE AT PHILADELPHIA MINT.

In July, 1917, a 1,000-pound, 125-kw., 110-volt Rennerfelt began operation at the Philadelphia Mint. The director of the mint⁹ has published some data on the operation of the furnace and has kindly

⁸Trans. A. S. Meeting of Manufacture Steel Industry, Iron Age, vol. 107, 1921, p. 69.

⁹Engel, E. P., Annual report of the director of the mint for the fiscal year ending June 30, 1918, Trans. Inst. Min., No. 2822, p. 11.

furnished other information which is included below. The furnace usually ran 24 hours a day, and in some 50 weeks of regular operation produced over 1,300 tons of coinage alloys—cupronickel, bronze, and silver. The average power consumption per net ton of product in this period was 500 kw. h. for cupronickel, 300 for bronze, and 200 for silver, these figures including all operation, whether on one 8-hour shift or on 24-hour operation.

CUPRONICKEL.

On cupronickel, which is 75 per cent Cu and 25 per cent Ni, a typical 24-hour run shows 10 heats of 1,000 pounds, or 5 tons melted at 440 kw. h. per ton. On 8-hour operation, three heats, $1\frac{1}{2}$ tons can be made at 650 kw. h. per ton.

The net metal loss on cupronickel is one-fourth of 1 per cent. While there are no volatile metals in this alloy to be lost by vaporization, in order to get the best quality of metal it is essential, notwithstanding that the atmosphere of the furnace may generally be reducing, to keep the furnace tightly closed against the entrance of air.

It was thought that the heat loss and the oxidation due to double pouring made desirable rigging the furnace to pour direct into the bar molds, though a ladle with a "teapot" spout helped somewhat. It was decided that Rennerfelt furnaces to be installed thereafter at the mint should have automatic electrode control and should be built to tilt around the spout for direct pouring.

The cupronickel melts proved to be homogeneous without stirring, as in this alloy both components are mutually soluble and have no tendency to segregate.

The melting cost on cupronickel is given as \$9.45 per net ton, which is less by 50 per cent than the cost in gas-fired crucible furnaces.

COINAGE BRONZE.

On coinage bronze, which is 95 per cent Cu and 5 per cent Sn and Zn, about 4 per cent Sn and 1 per cent Zn, a typical 24-hour run shows 12 heats of 1,065 pounds each, or about $6\frac{1}{2}$ tons melted at 325 kw. h. per ton.

On 8-hour operation the output is about 3,500 pounds at 400 kw. h. per ton. The metal losses seem to run slightly higher than the 0.3 per cent loss regularly obtained in the mint crucible-furnace practice, going up to one-half or three-fourths of 1 per cent, perhaps owing to greater volatilization of zinc, but it is thought that with experience this can be kept down to the 0.3 per cent figure. Such a figure in either type of furnace would hardly be obtained in ordinary foundry practice; it was obtained at the mint because of the workmen's skill, gained by working on the precious metals, in saving every drop or

scrap of metal. The mint considers that the furnace would give an excessive loss of zinc on high-zinc alloys.

No trouble is experienced in getting a homogeneous product on coinage bronze, and even coinage silver (90 parts Ag and 10 parts Cu) has shown uniformity in samples taken from top and bottom of the melt. No segregation would be expected in the bronze alloy, though the handling of coinage silver to avoid segregation is more of a task.

The furnace roof and lining was silica brick; outside the 9-inch silica brick on the sides is 2½-inch fire brick, then 1-inch asbestos cement. The hearth is of ganister bonded with water glass. The life of the lining—1,277 heats for the furnace body and 800 to 1,000 heats for the roof—is amazingly good in view of the pouring temperatures of cupronickel, the material chiefly melted.

The long life of the silica roof is doubtless due, in part at least, to the furnace having been normally run 24 hours a day and never allowed to cool unless repairs were to be made.

On all of the alloys melted the mint figures a saving of 40 per cent in melting cost over former fuel-fired practice. The output per furnace tender was doubled over that from crucibles.

In a later report¹⁰ of the director of the mint further data on the operation of the 1,000-pound Rennerfelt are given. In melting silver coin the furnace handled 18,000 pounds, or 9 tons, in 24 hours. In melting 1,585 tons of silver coin the average power consumption was 177.4 kw. h. per ton, 24-hour operation, the cost for electric power per ton being over 50 per cent less than the corresponding cost of gas per ton for melting in crucible furnaces. The furnace did not require either relining or a new roof during the 3,191 heats required to melt the 1,585 tons of silver coin. The metal losses in melting silver coin were approximately one-tenth of an ounce per 1,000 ounces, one part in 10,000, or 0.01 per cent, a most remarkable figure and one lower than is obtained in crucible melting. The director of the mint says: "This is due to the fact that the furnace construction and the absence of flue prevent metal from going up the chimney, and, too, the method of pouring is cleaner and fewer mechanical losses are suffered."

After melting the run of silver coin the original 1,000-pound furnace was replaced by another having automatic electrode control for the side electrodes and tilting on the lip for direct pouring into molds. This furnace ran 286 heats of cupronickel, one heat of pure copper made to clean out traces of nickel, and 445 heats of coinage bronze, or a total of 732, when it was shut down until the installation

¹⁰ FARR, S. T., Annual report of the director of the mint for the fiscal year ending June 30, 1919; *STANDARD ENGINEERING*, No. 2945, p. 12; see also Coleman, H. D., Melting in a Rennerfelt electric furnace; *Metal Ind.*, vol. 18, 1920, p. 406.

of another similar furnace of 1-ton capacity, as shown in Plate X, A (see p. 148), was complete. Another 1,000-pound furnace was ordered for the San Francisco Mint. The electrode consumption is $2\frac{1}{2}$ to 4 pounds per ton of metal melted, depending on the character of the charge. Though a week's run demonstrated that the lip-pouring device allowed pouring direct into molds with precision, it was concluded that ladle pouring gave better ingots and was more practical. A 200-pound ladle is put on a car, rolled under the spout, filled, and pulled to the molds, where it is lifted in a shank and hung in a bail on a hoist, the metal then being poured into molds resting on a turntable. Use of larger ingot molds, being poured simultaneously, and of larger ladles are to be tried to shorten the pouring time.

The makers of the Rennerfelt furnace, however, state that the casting table or device by which the molds are spotted in front of the spout did not work very well, retarded pouring too much, and kept the spout open too long. They consider nose tilting desirable if the furnace can be emptied very rapidly.

As the work at the mint demands the highest quality of product, this point, as well as the mint's conclusion that the furnace must be tightly closed to prevent oxidation and the resultant lowered quality of product, deserve close consideration by users of electric furnaces. The Gorham Mfg. Co., Providence, R. I., has installed a Rennerfelt for melting silver.

PERFORMANCE OF RENNERFELT FURNACES ON LEADED BEARING BRONZE.

Besides the Snyder furnaces, the Chicago Bearing Metal Co. operated two 300-kv. a., 1-ton capacity Rennerfelt furnaces on leaded bronze, 70 to 75 per cent Cu, 15 to 20 per cent Pb, about 6 per cent Sn, balance Zn, Sb, Fe, etc. The furnaces take current at 100 to 110 volts. In a test of these furnaces in 1917 in 130 heats the average power consumption was about 285 kw. h. per ton on 20-hour operation, and from the data full 24-hour operation should give a figure of about 270 kw. h. per ton. The output was lower than that from the Snyder furnaces, 10 to 11 tons being obtained a day. The rate of power input to the Snyder furnaces was considerably higher than that to the Rennerfelts. The metal losses seemed to be somewhat lower than in the Snyders.

The Rennerfelt furnaces had loosely fitting water-cooled bronze sleeves about the side electrodes at the entrance to the furnace, the side electrodes being 3-inch diameter graphite and the top one 4-inch diameter. Trouble was encountered from deposition within these sleeves of metallic zinc, or zinc oxide, and lead and antimony or their oxides. Then the electrodes would bind, and as the electrode supports and adjusting mechanism were not very rigid, a twisting stress was set up and the electrodes, especially the side or 3-inch electrodes,

broke easily. The actual electrode consumption ran at about 5½ pounds per ton of metal melted, plus about 2 pounds per ton more lost by breakage. Damage to the water coolers was also common. Hence early in 1918 the use of the water coolers was abandoned and the electrodes passed through large holes, about 6 by 8 inches, in the furnace walls. This cut down the sticking of the electrodes, but made them oxidize more readily, the joints became weak, and the electrode consumption increased greatly, being nearly three times as much the first month after the change as it was before. In 57 heats watched by a representative of the bureau in 1918, two months after the coolers were eliminated, 33 electrode sections had to be added because of breakage, usually at the joint, which had been weakened by burning. The broken sections were not always a total loss, but had to be rethreaded into shorter sections.

The electrode consumption has since been reduced by using 4-inch electrodes on the sides as well as on the top, these electrodes being large enough to withstand the burning of the joints without becoming excessively fragile.

The Rennerfelt furnaces are lined with the same mixture of carborundum fire sand, fire clay, and molasses as the Snyders, and have fire-brick roofs. At present the hearth lasts about 400 heats of 1,500 pounds each and the roof 100 to 180 heats, on 8-hour, one-shift operation. While on 20-hour operation in 1918 the cost of materials, labor not included, for Rennerfelt roofs and linings, during the melting of 816 tons, three-months' output, two furnaces, averaged 60 cents per ton. The lining life at that time was not as good, on the basis of tons melted, as in the Snyder, whereas the later figures, given above, show it to be slightly better.

Used with large openings about the electrodes the Rennerfelt furnace can not be kept tight, and in this condition gives off as much fume as the Snyder. The metal losses in tests of Rennerfelts, operated open, were somewhat below those reported in tests of the Snyders; 18 heats of 1 ton each gave 35,043 pounds of metal and some 921 pounds slag, from which about 160 pounds metal would be recovered; the gross loss on 36,000 pounds was 957 pounds, or 2½ per cent, and the net loss about 800 pounds, or 2¼ per cent. No account is here taken of dirt or other nonmetallic in the charge, but it was thought that the charge to the Rennerfelts in the 1918 tests was a little cleaner than that to the Snyders. Though the true difference between the net metal losses in the Snyders and the Rennerfelt, both operated unsealed and open at spout and electrodes, may not be in favor of the Rennerfelt quite as much as the test figures—4.5 per cent Snyder, 2.25 per cent Rennerfelt—it is believed that the Rennerfelt has a lower metal loss than the Snyder.

In the 1918 tests the Rennerfelts were giving only seven to eight 1-ton heats in 19 to 20 hours, while the Snyders were giving 13 heats of the same weight in the same time. The Snyder power consumption was only about 280 kw. h. per ton, whereas the Rennerfelts on 57 1-ton heats used 18,860 kw. h., or about 330 kw. h. per ton. On a full 24-hour schedule the Snyders seemed capable of melting at 265 kw. h. per ton and the Rennerfelts seemed capable of melting at 300 kw. h. per ton.

Several factors contribute to the lower output and higher power consumption of the Rennerfelts. The Snyders could be charged more rapidly on account of their suitability for mechanical charging, but the Rennerfelts have to be charged by hand. The use of small uncooled electrodes and the consequent loss of time from excess breakage handicapped the Rennerfelt, and in that furnace much heat was lost about the electrode openings. The greatest factor in the relative slowness of the Rennerfelts was, however, the low rate of power input, the Rennerfelts being run at about 200 kw. and the Snyders averaging 310 kw.

The power factor of the Rennerfelts, however, was satisfactory, being around 75 on the 60-cycle current used, whereas that of the Snyders is much lower.

Much better results as to rate of production were later obtained with the Rennerfelt furnaces, after the electrodes were all made 4 inches in diameter, and after adopting the plan of basing the pay of furnace tenders on a certain number of heats instead of paying by the hour. This plan has cut about two hours off the running time, the furnaces being operated one shift only during most of 1919, because the furnace tenders hold a much higher power input than before, take more care, and are less likely to break electrodes when responsible for the time lost in replacing them. One negro furnace tender takes care of one furnace.

Care is taken to pour the metal from the furnace as soon as it is ready, pouring taking 10 minutes. Charging is still done by hand, as the Rennerfelt furnace is not suited to mechanical charging. Two men charge in five minutes.

Eight 1,500-pound heats, or 6 tons, are now obtained in a trifle over eight hours. In 49 days one furnace made 394 heats, 296½ tons, in 395½ hours; the other made 390 heats, 292 tons, in 400½ hours, or a total of 588 tons in 796 hours, or about 1,500 pounds per hour. The power consumption in 8-hour operation, hand control, was about 320 kw. h. per ton. These figures show a lower output and a slightly higher power consumption than by the Snyder and are accounted for by the transformers at the Rennerfelt furnaces being rated at 300 kv. a., whereas those at the Snyders are rated at 700 kv. a. The Rennerfelt transformers overheat at a rate of power input to the

furnaces that will give one 1,500-pound heat, including pouring and charging, per hour at 320 kw. h. per ton, and the attempt to maintain so high a rate of production was deemed unsafe. If pouring and charging take 15 minutes, if the power is on 45 minutes per heat, and 240 kw. h. are used, then the average power input is 320 kw.; at 75 per cent power factor this input is over 425 kv. a. instead of the 300 kv. a. at which the transformers are rated. It was thought that if automatic electrode controls were installed on the Rennerfeldts one furnace tender could operate both furnaces.

Prices quoted on Rennerfelt furnaces, including transformers, meters, etc., in February, 1920, were as follows, for 60-cycle current:

TABLE 43.—*Prices of Rennerfelt furnaces.*

Type.	Capacity.	Kv. a.	Price.
O	300 to 500 pounds.	100.	\$5 380.
IA	1,000 pounds.	150 to 200.	\$12,000.
IIB	1½ tons.	300 to 500.	\$16,000 to \$20,000.
IVA	3 to 4 tons.	800 to 1,200.	\$26,000 to \$30,000.
VA	5 to 6 tons.	1,400 to 1,800.	\$35,000 to \$46,000.

Type O is hand controlled; all the others have automatic electrode control. At the prices quoted types O, IA, and IIB have central trunnions. Types IVA and VA are set on rockers. Types O and IA are tilted by hand, the rest by motor.

RE-PEL-ARC FURNACE, OR VON SCHLEGELL REPELLING-ARC FURNACE.

A recent development is the von Schlegell "repelling-arc" furnace,¹¹ manufactured by the Re-pel-arc Furnace Co., of Indianapolis, which can be operated either as a direct-arc or an indirect-arc furnace. Figure 29 shows a schematic diagram of the furnace. The furnace is normally three-phase (though single-phase current with two electrodes can be used) and is designed for 220 volts. The electrodes, instead of hanging vertically, are supported on pivots and supplied with counterweights, so that when no current is on the three electrodes hang at slight angles, touching at their tips. When the current is thrown on, the repulsive action due to the current flow moves the electrodes apart, thus starting the arc. Similarly, if the arc is broken while the current is on it will restart itself. The length of the arc, and hence the power input, is regulated by the position of the counterweights. The arc is therefore largely self-regulating.

¹¹ Von Schlegell, F., Electric furnace with repelling arc: *Iron Age*, vol. 106, 1920, p. 1124; *Mech. Industry (London)*, vol. 18, 1921, p. 23; U. S. Patent 1,352,541, Sept. 14, 1920.

If the cluster of electrodes is placed so far above the charge that the arc path from one electrode tip to another is shorter than that

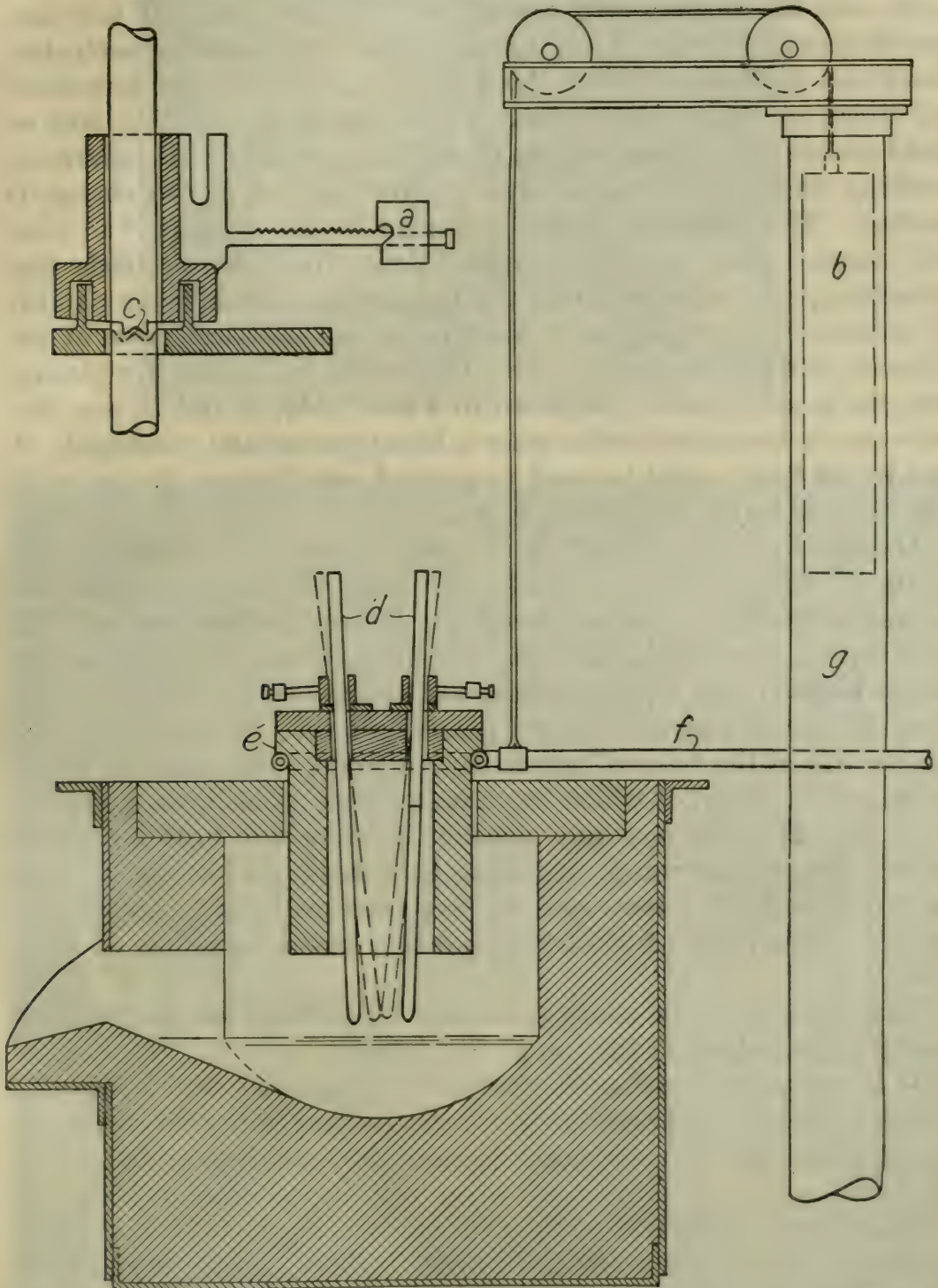


FIGURE 29.—Von Schlegell "repelling-arc" furnace: *a*, current-regulating weight; *b*, counter weight; *c*, pivoted electrode-holder showing gas-tight joints; *d*, electrodes; *e*, refractory sleeves; *f*, pipe support; *g*, mast. By raising torch arc is drawn between electrodes, instead of between electrodes and metal, thus moving center of temperature above metal without affecting operation of the arc.

from one tip to the bath and back to another tip, the arcs will be drawn among the electrodes, and the furnace will operate as an

indirect-arc furnace. If the electrode cluster be lowered so that the electrode tips are close to the bath, the arcs will be drawn to the path and the furnace will operate with a direct arc. If the electrodes burn off evenly, so that independent adjustment of each electrode can be dispensed with, this scheme may prove a simple method of direct-arc furnace operation. The electrode, of graphite, may be held above the charge to give an indirect arc while the charge is melting and be lowered to give a direct arc when the charge is melted. The electrode cluster is termed by its inventor "an electric torch," since the arc is thrown down from the electrode tips something after the fashion of the Rennerfelt fleur-de-lis arc, and it is pointed out that this torch contains all the electrical parts of the furnace, the balance being merely the hearth and shell. By placing two shells side by side, as shown in Plate XIII, *A* and *B*, one furnace can be heated while the other is being poured and recharged. A gas or oil flame could be used to preheat one furnace charge while the other is being electrically heated.

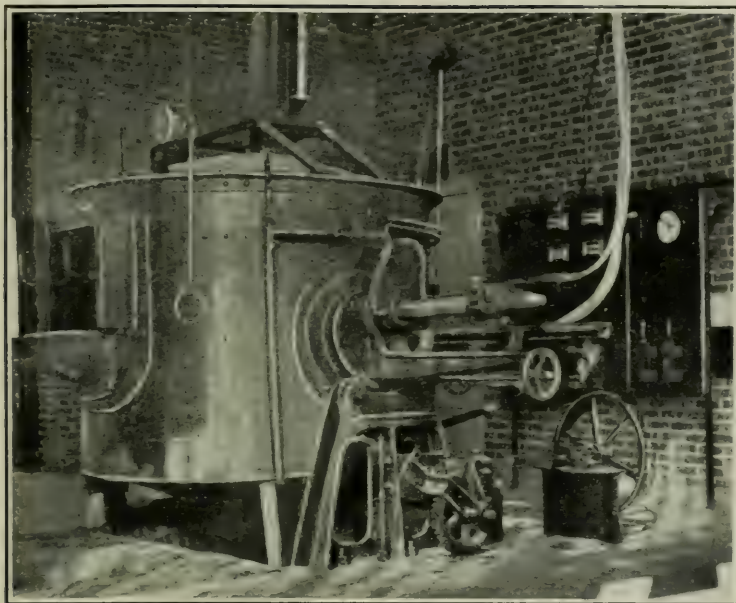
On red brass, 85:5:5:5, half heavy scrap, half borings, seven heats of 300 pounds were made in a day. The furnace was preheated half an hour before charging. Three hundred and seventy-five kw. h. were used, including the preheat, and 2,112 pounds of metal melted; that is, the furnace ran at the rate of 357 kw. h. per ton. Electrode loss was about 3 pounds per ton. No data are given on the life of the "sleeve" about the electrode. The time for a heat averaged one hour, of which five minutes were spent in charging and pouring. It takes one and one-fourth hours per heat on Monel metal. In another run on red brass half ingot, half scrap, 11 heats of 300 pounds each were said to have been made in 10 hours, at a power consumption of 350 kw. h. per ton, and a metal loss of 1 per cent.

The furnace can be charged rapidly by pulling out the "torch" and charging through the top of the furnace.

It is not stated whether the furnace was operated with a direct or indirect arc on red brass, but since the makers state that on Monel metal or steel the arc is brought down to the bath, it is probable that it is operated as an indirect arc when melting red brass or bronze.

One of the Rennerfelts at the Chicago Bearing Metal Co. has been changed over to take a 450-kw. "torch." This furnace is shown in Plate XII, *B*. The metallurgical behavior of the furnace may be expected to be that of any direct-arc furnace when used as a direct-arc furnace and of any indirect-arc furnace when used as an indirect-arc furnace. It could be used on bronze and Monel metal but not on yellow brass high in zinc.

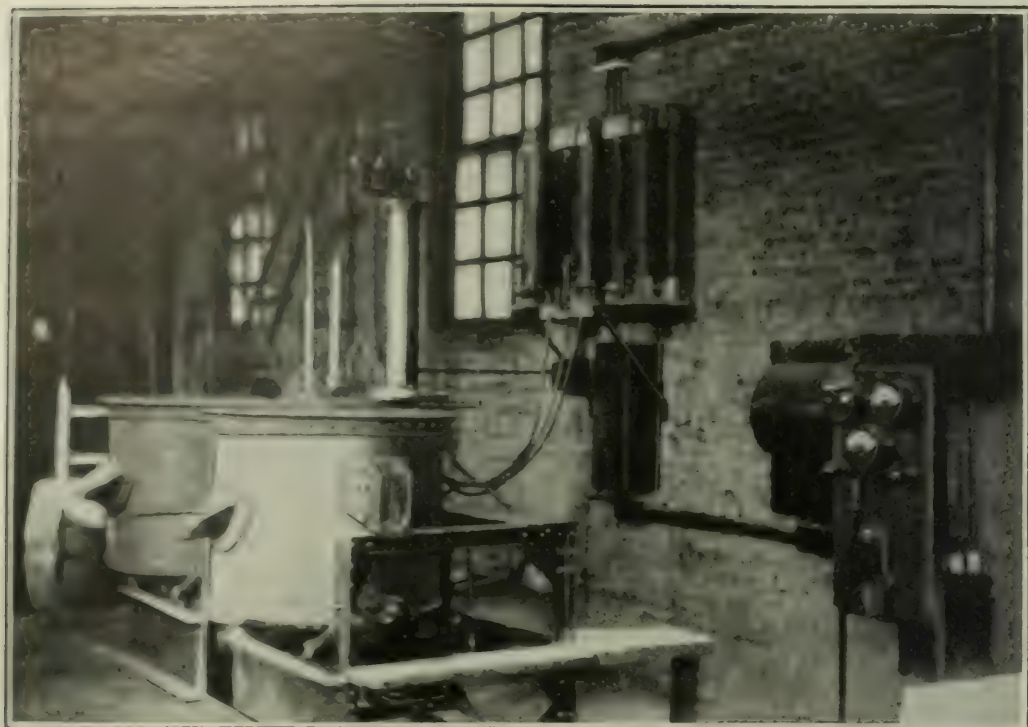
All the yellow brass and manganese bronze made by the Chicago Bearing Metal Co. is still melted in crucible lift-out oil furnaces, the



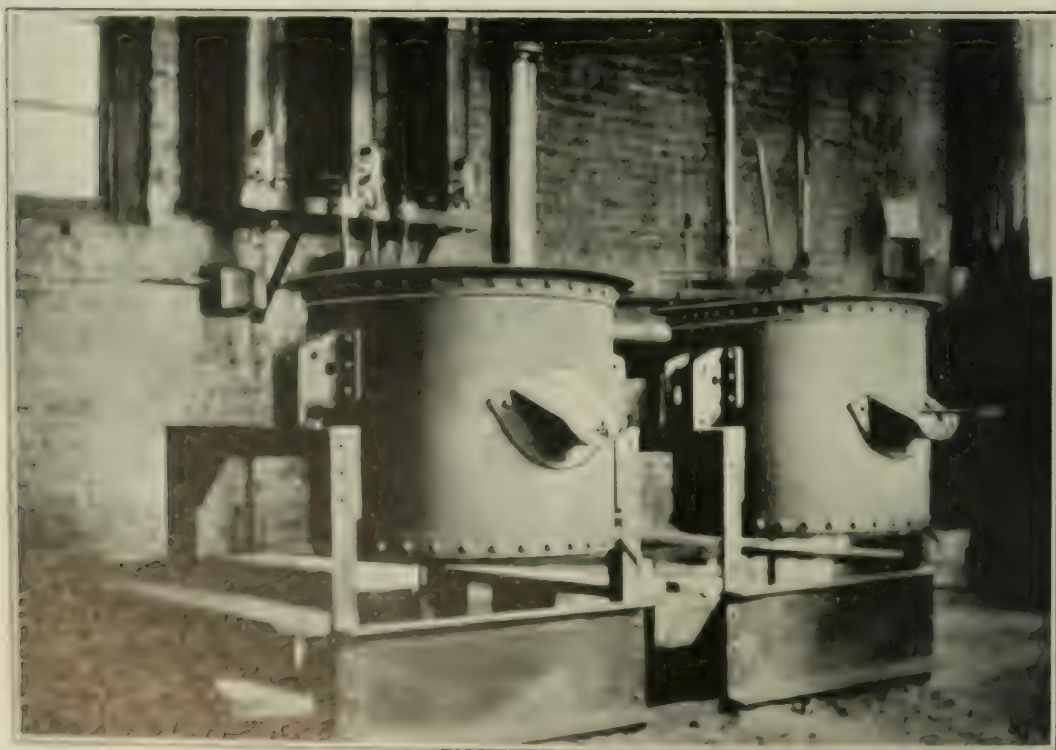
A. TRUNNION-TYPE RENNERFELT FURNACE.



B. RE-PEL-ARC ELECTRIC TORCH IN AN OLD RENNERFELT SHELL AT THE PLANT OF THE CHICAGO BEARING METAL CO



A. REPELLING-ARC FURNACE WITH TWO SHELLS, SIDE VIEW.



B. REPELLING-ARC FURNACE WITH TWO SHELLS, FRONT VIEW.

various direct and indirect arc furnaces not being of any more use for alloys high in zinc than the open-flame oil furnaces would be.

A repelling-arc furnace is being tried out by the Bridgeport Brass Co., but it is stated ¹² that it has not yet been very successful.

SUMMARY OF STATIONARY INDIRECT-ARC FURNACES.

It has been shown that although stationary indirect-arc furnaces, of which the Rennerfelt is the best known, have been used on yellow brass by running at low power input, where excessive zinc loss was a minor factor because of electric power being cheaper than fuel, yet under American conditions it would be wasteful to use such furnaces for melting alloys high in zinc. Even in the United States an alloy of about 20 per cent zinc has been commercially melted in a 600-pound furnace with a metal loss slightly less than in former fuel-fired practice, but the furnace has given trouble through the electrodes sticking from condensed zinc. By analogy with the behavior of the direct-arc furnace, the 600-pound size of which could be kept tight when melting a high lead alloy, though the 1-ton size could not, it is doubtful whether a 1-ton indirect-arc furnace can be satisfactorily operated on even the 20 per cent zinc alloy at a rate of power input that will give good figures for production and power. The 1-ton indirect-arc furnace even gave trouble when operated tightly closed on a 15 to 20 per cent lead alloy and finally had to be operated open with correspondingly larger metal losses.

Stationary indirect-arc furnaces are highly suitable for Monel metal, cupronickel, pure copper, silver, bronze, red brass, and similar alloys containing up to, say, 10 per cent zinc or 15 per cent lead. On alloys high in volatile metals this type of furnace operates at a metallurgical disadvantage, which increases with the amount of volatile material; hence operation on yellow brass is entirely impractical under American conditions, a fact that is understood and admitted by the makers of the Rennerfelt. Though the furnace has a wide field—a much wider one than that of the direct-arc type—it is not useful in the important field of rolling-mill work on alloys high in zinc.

The indirect-arc furnace ranks high as regards reliability, reasonable upkeep, and rate of production. Under similar conditions its rate of production is not quite as large as that of the direct-arc type, nor is its thermal efficiency quite as good, but in both these respects it is decidedly better than furnaces of the reflected-heat type, such as the granular resistor and smothered arc. Its field is smaller, however, than that of those types. Its electrical characteristics are satisfactory. The load is not so steady nor its power factor so high as those of the reflected-heat type, but both are better than in the

¹² Webster, W. R., personal communication, Aug. 24, 1921.

direct-arc type. The Rennerfelt takes three-phase current, and hence is free from the drawbacks of a single-phase load. All in all, the stationary indirect-arc furnace is a very useful type, provided it is used on work for which it is fitted.

MOVING INDIRECT-ARC FURNACES.

STASSANO FURNACE.

Though the earliest indirect-arc furnaces suggested were those of Pinchon (1853)^{12a} and Siemens (1878), followed by that of Moissan, used to such good advantage in the classical researches of that great Frenchman, the first commercial indirect-arc furnace was invented by Stassano. Stassano first designed (in 1898) a shaft furnace for making steel direct from iron ore; then he designed a stationary hearth furnace, but his first furnaces to attain commercial success were designed, as illustrated by figure 30, to be kept in motion.¹³

These furnaces were built in the form of an upright cylinder with its vertical axis at a slight angle from the vertical. The whole furnace was rotated, so that both the rotary motion and the tilt of the axis tended to swash the metal from side to side.

Stassano says¹⁴ that the "agitation increases the activity of the reaction producing the refining, and shortens the time, thus making possible work on a full charge without risk of overheating the chamber or damaging the lining." Stassano's prime object in rotation thus seems to have been assuring a better contact between the ore and reducing agent in smelting iron ore, or between the metal and slag in refining steel. Of course, the continuous rotation of the furnace body involved the use of sliding contacts in the electric circuits and of joints in the water-cooling connections. Such contacts in circuits carrying the high amperage required by good-sized electric furnaces are notoriously difficult to maintain and such joints in water connections are hard to keep tight. Stassano¹⁵ therefore had to substitute an oscillating motion and abandon complete rotation of the furnace in order to overcome these difficulties.

Rodenhauser¹⁶ says: "If any security is desired for a complete uniformity of the material in its several layers, it is not possible to dispense with the mechanical bath circulation."

^{12a} See Rodenhauser, W., and Schoenawa, J., translated by vom Baur, C. H., *Electric furnaces in the iron and steel industry*; 1917, p. 4.

¹³ Best production in the electric furnace: *Electrochem. Ind.*, vol. 1, 1903, p. 247; Stassano, E., U. S. Patent 799,105, Sept. 12, 1905; application Apr. 9, 1902.

¹⁴ Stassano, E., The application of the electric furnace to siderurgy: *Trans. Am. Electrochem. Soc.*, vol. 15, 1909, p. 70.

¹⁵ Stassano, E., U. S. Patents 1,024,657, Apr. 30, 1912, application Aug. 7, 1911; 1,000,490, Apr. 21, 1913, application Nov. 29, 1912, and 1,105,859, Aug. 4, 1914, application Oct. 25, 1912.

¹⁶ Rodenhauser, W., and Schoenawa, J., translated by vom Baur, C. H., *Electric furnaces in the iron and steel industry*; 1917, p. 118.

Schmelz¹⁷ says that an oscillating furnace with the double-trunnion suspension, like that of a ship's compass, does away with the former complications of the cable and water connections of the rotary

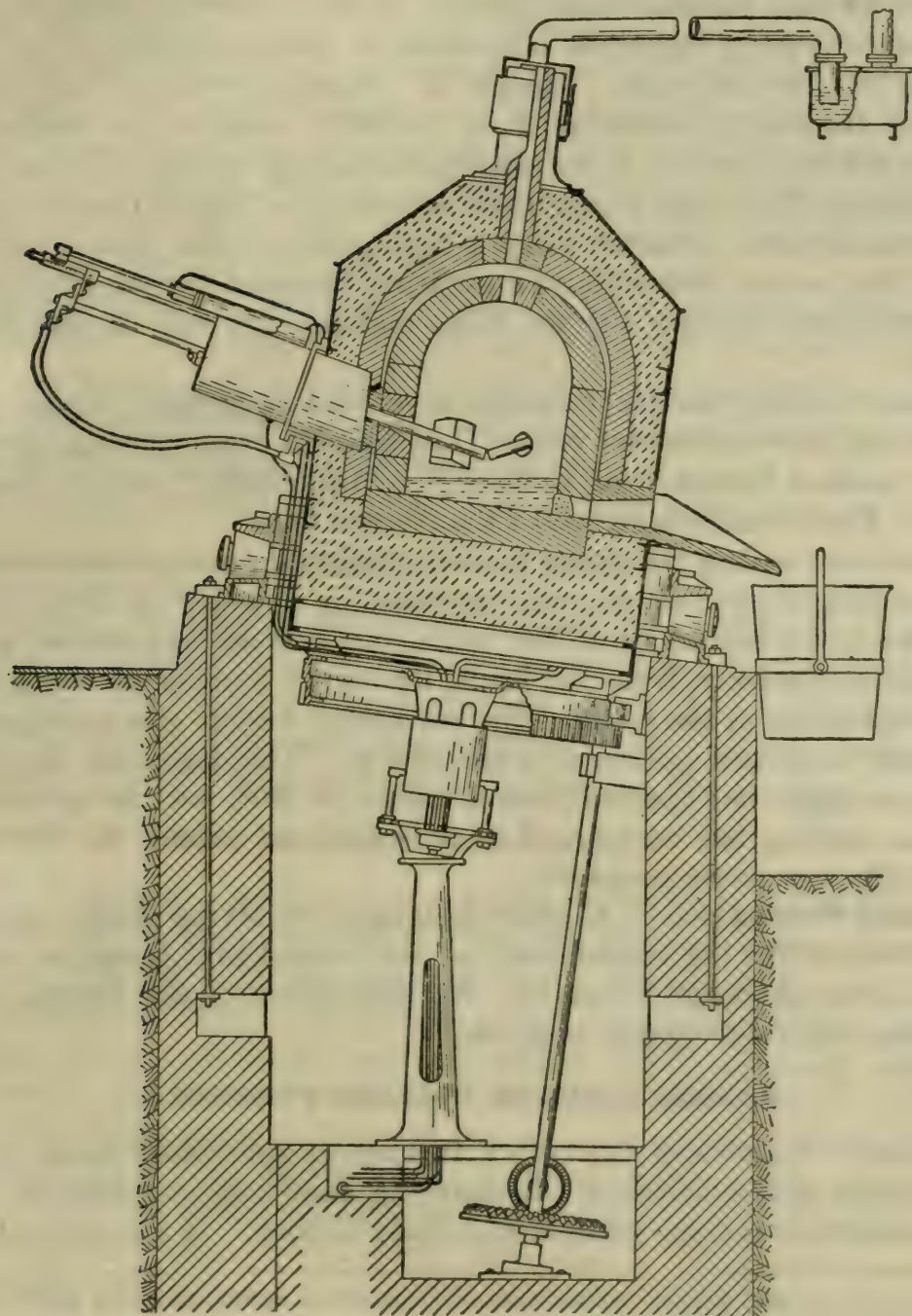


FIGURE 30.—Elevation of gyrating three-phase Stassano furnace.

furnace. It can also be tilted to pour, while the earlier form had to be tapped. The oscillating or gyrating design of the Stassano is very like the later design of the Thomson zigzag-resistor furnace.

¹⁷ Schmelz, E. M., A new electric steel-casting plant: Met. and Chem. Eng., vol 11, 1913, p. 709.

Keeney¹⁸ asserts that agitating the bath of steel had not proved of great value for steel and had been abandoned in the more recent Stassano furnaces.

The moving Stassano steel furnace, as far as careful study of the literature reveals, has never been tried or even suggested by its inventor for use on brass. Though the Stassano motion would tend to mix the metal somewhat, it is doubtful whether the relatively slight motion would mix the charge thoroughly enough to overcome in melting alloys high in zinc the overheating of the surface through the concentrated radiation from a high-powered arc. One furnace, the Volta, which is essentially a gyrating Stassano furnace, has very recently been brought out for brass melting. It will be described later.

Other moving electric furnaces have been suggested, though not especially, save in the case of the Thomson, for brass melting, among them those of Burton¹⁹, of Johnson²⁰, of Ischewsky²¹, and of Thomson.²² These furnaces are all of the resistor type.

Another rotating resistance furnace, designed among other things, for melting copper alloys, was described by Braun²³ in 1904. The resistance was embedded in the walls, and current was carried to it by sliding contacts, from the leads, through a number of electrodes also embedded in the walls. The refractory hearth was corrugated in order to secure agitation of the charge. The design of the furnace, as might be expected from a design of 1904, was not practical and as nothing has been heard of it beyond the patent, the furnace probably was never operated.

Rideal²⁴ states that F. Clerque designed a revolving electric radiation furnace for the manufacture of ferronickel that is said to have been in use at Essen, Germany. No description of the furnace nor reference to a description is given.

BENSEL RESISTOR ROLLING FURNACE.

Bensel²⁵ describes a laboratory furnace of spheroidal shape with the longer axis horizontal. A charging door was provided on the circumference and the furnace was tilted to pour. It was also rolled

¹⁸Keeney, O. J., and Keeney, R. M., Electric furnaces for making iron and steel: Bull. 67, Bureau of Mines, 1910, p. 82.

¹⁹Burton, G. D., U. S. Patent 679,452, July 30, 1901.

²⁰Johnson, W. M., U. S. Patent 825,058, July 3, 1906.

²¹Ischewsky, W. M., U. S. Patent 847,003, May 12, 1907.

²²Thomson, J., and Fitzgerald, E. A. J., U. S. Patent 950,878, Mar. 1, 1910; Thomson, J. T. S. Patent 804,000, Mar. 1, 1910.

²³Braun, L., French Patent 239,242 of June 22, 1904.

²⁴Rideal, E. G., *Electrometallurgy*, 1919, p. 150.

²⁵Bensel, E., Beiträge zur Verringerung der Metallverluste beim Messingschmelzen: *Metallurgie*, vol. 9, 1912, p. 167; *Chem. Abh.*, vol. 6, 1912, p. 3256; *Jour. Soc. Chem. Ind.*, vol. 31, 1912, p. 479; *Jour. Inst. Metals (British)*, vol. 8, 1912, p. 353; *Jour. Franklin Inst.*, vol. 272, 1912, p. 150.

back and forth while operating to mix the metal. A direct current was tried as the source of heat, but was said to be unsuitable as the positive electrode burned off too quickly. A resistor was therefore used, the carbon-rod resistor running through the long axis. The furnace held 20 kg., or 44 pounds, of metal and took an average of 44 volts at 530 amperes when hot. Bensel melted 44 pounds of a 70:30 brass made from new metals in 1 hour and 35 minutes, from a cold start, using 35.4 kw. h. He poured 19.3 kg., or 42½ pounds, of brass, a loss of 3.5 per cent, but he figured that much soaked into the lining and that the true loss was under 1 per cent.

By a peculiar process of calculation involving several assumptions he decided, on the basis of a single heat, that the furnace on an all-day run would melt at 7.3 kw. h. per 100 pounds, or 146 kw. h. per ton, a figure lower than the generally accepted value for the power theoretically needed at 100 per cent efficiency.

No further development of the Bensel furnace has been recorded.

CARRERÈ FURNACE.

Carrerè,²⁶ however, described an indirect-arc furnace having the form of a cylinder lying on its side, the electrodes entering through the ends. The body of the cylinder was rotated while the end walls were stationary, they and the electrodes not revolving with the furnace. This furnace was not suggested for use on brass.

WEEKS ZINC FURNACE.

The Weeks zinc furnace²⁷ is a horizontal cylinder heated by an indirect arc or arcs, but differs from the Carrerè furnace in that part of the end walls can move with the furnace body; only the electrodes and rings or trunnions about them that contain water coolers for the electrodes and an offtake for zinc vapor remain stationary; the furnace aside from these parts may revolve. A tap hole or pouring spout is shown in the patent, closed by a plug which is held in tightly to withstand the pressure of the molten zinc.

In both the Carrerè and Weeks furnaces the stationary ends and the revolving body involve many difficulties in maintaining a gas-tight seal over so large a joint and in sealing the charging door to prevent leakage of metal when the furnace is revolved. The charging door of the Weeks, on account of lack of space at the ends above the melt, was placed on the circumference of the drum.

No account of any actual experiments with the Carrerè furnace has been found in the literature. The Weeks zinc furnace, as has been previously stated, was tested at the plant of the General Electric Co. at Schenectady, N. Y., for zinc smelting; also one or two

²⁶ Carrerè, J. M., U. S. Patent 726,860, May 5, 1903.

²⁷ Weeks, C. A., U. S. Patent 949,511, Feb. 15, 1910; application filed Sept. 3, 1908.

heats of copper were made in it. The patent specifications for the Weeks furnace make mention of revolving the body of the furnace to interchange the roof and hearth, the advantage being in "uniformly wearing the lining and applying substantially all the heat to the contents." But in a published description of the furnace Weeks²⁸ makes no mention of revolving the furnace or of the effect of stirring on metal losses. He assumes a figure for metal losses on yellow brass, but it is not based on any experiments.

Hansen,²⁹ in describing the Weeks zinc furnace, says:

The drum was mounted on rollers which could be motor-driven. . . . The heat was supplied by radiation from an arc and the rotation of the furnace body was intended to equalize temperature of the furnace lining by periodically bringing all the parts of it in contact with the charge. Incidentally, thorough mixture of the charge would be secured by this rotation. The copper-melting experiments were of purely secondary consideration to Mr. Weeks. . . .

Hansen asserts that in melting zinc with this furnace the electrodes become soldered in place by condensed zinc and could not be adjusted to regulate the arc. Mr. Weeks has informed one of the writers that the furnace, though designed to rotate, was not rotated in the copper-melting experiments. No experiments were made with brass, and the effect of stirring on the superheating of the surface of the melt and on the loss of zinc was evidently not impressed on Hansen by the few experiments that were made; instead of continuing to experiment with the Weeks furnace Hansen built the three-phase Stassano-type furnace, which was tested on yellow brass borings at the Schenectady plant.

IMBERT ZINC FURNACE.

Another zinc furnace, the Imbert,³⁰ designed at about the same time as the Weeks, the patent application being made in Germany only two days before that of the Weeks in this country, greatly resembles the Weeks furnace; the chief variation is the leaving of a larger clearance space between the stationary part of the end wall and the revolving part, and the use of this space as offtake for zinc vapor. The Imbert furnace has not been suggested for use on brass.

HULDT FURNACE.

The Weeks and Imbert furnaces were designed for the reduction of zinc from its ores or for its purification by distillation. A more recent patent³¹ utilizes an indirect-arc furnace built as a horizontal

²⁸ Weeks, C. A. Melting nonferrous metals in an electric furnace: *Met. and Chem. Eng.*, vol. 9, 1911, p. 383.

²⁹ Hansen, C. A. Electric melting of copper and brass: *Trans. Am. Inst. Metals*, vol. 6, 1903, pp. 117, 126.

³⁰ Imbert, J. H. German Patent 219,515 of Mar. 1, 1910; application filed Sept. 1, 1908.

³¹ Huldt, E. L. S. Patent 1,566,408, May 21, 1908, application filed Apr. 3, 1917, *West Electric Metallurgical Abstracts*; British Patent 105,558 of Mar. 21, 1918 (containing data, London, Apr. 6, 1916).

cylinder, not for distillation of zinc, but for the melting of "blue powder," the oxide film on the surface of the particles being rubbed off by the motion of the particles sliding on each other in a rotating furnace. It is said that the drum may have a rocking motion if desired. The furnace construction is not explained in detail in this patent.

ROCKING OF FUEL-FIRED BRASS FURNACES.

Rotary fuel-fired furnaces, such as the cement kiln, and rotary roasting furnaces³² are well known. In a number of brass foundries it has been found that time could be saved in the operation of open-flame oil furnaces by rocking the furnace back and forth by hand during the last few minutes of the heat, so that the hot walls just above the metal are washed by the metal, and give up some of their stored heat to it. Mechanically rotating and rocking oil-fired brass furnaces are now on the market.³³

Rennerfelt³⁴ says that some "of the heat absorbed by the walls may be recovered by tilting the crucible, or the hearth, to bring the charge into contact with the heated walls, thereby absorbing some of the heat."

Rennerfelt also mentions the possible use of a projection in the furnace bottom to stir the metal when tilting the furnace. No provision is made for continuous tilting, nor, so far as known, has any Rennerfelt furnace been built with such a projection.

While moving electric furnaces of various types had been known, they had not been tried for brass melting save for a couple of heats in the Bensel resistor furnace, and though fuel-fired brass furnaces had been operated with slight stirring they had not been so operated mechanically. As far as can be ascertained, the Bureau of Mines was the first to make actual experiments on brass melting in an electric-arc furnace rocked or otherwise moved to stir the metal in order to prevent surface overheating of the melt; the first laboratory heat was made on August 25, 1915, in the electric furnace laboratory of Cornell University, which by a cooperative agreement is used by the Ithaca field office of the bureau.

The fundamental idea behind the bureau's study of the rocking indirect-arc furnace for brass was that several of the essentials of an "ideal" electric brass furnace—ruggedness, simplicity in the hot zone, and ability to be run at a high rate of power input—were present in the indirect-arc type, and that the drawbacks—superheating

³² Canby, R. C., *Trans. Am. Electrochem. Soc.*, vol. 27, 1915, p. 65; Anonymous, *New foundry for making mill brasses: Iron Age*, vol. 107, 1921; Anonymous, *Makes asset of a building obstacle: Foundry*, vol. 49, 1921, pp. 29, 197.

³³ Compare *Metal Ind.*, vol. 16, 1917, p. 38; Jones, A., U. S. Patent 1,334,459; Advertisement, *Metal Ind.*, vol. 18, 1920, p. 3; Advertisement, *Foundry*, vol. 48, 1920, p. 102.

³⁴ Rennerfelt, I., U. S. Patent 1,076,518, Oct. 21, 1913, p. 2, line 50.

of the surface of the charge, consequent inability to keep the furnace tight on alloys high in zinc, too much heat storage to give perfect control of temperature, thermal losses through the roof and consequent troubles with refractories in the roof—would either be avoided or decreased by a stirring action brought about by rocking.

Inasmuch as the ordinary stationary indirect-arc furnace gives far less trouble from surface superheating than the direct-arc type, it was evident that the overcoming of this trouble by stirring would be easier and simpler in the indirect than in the direct arc type. Indeed, it is very doubtful whether any commercially attainable degree of stirring could sufficiently counteract the overheating of the metal directly under the arc in a direct-arc furnace.

LABORATORY ROCKING FURNACE.

The small laboratory furnace, a fire-brick-lined cylinder lying horizontally, with 2-inch diameter graphite electrodes entering at the ends of the furnace, was so mounted that it could be rocked back and forth while melting, as in Plate XIV. The single-phase indirect-arc ran at 50 to 75 volts and took about 30 to 35 kw. If the furnace was operated on alloys high in zinc without rocking, it acted like any other stationary indirect-arc furnace, being hard to keep tight, superheating the surface of the metal and giving too high metal losses. By rocking the furnace back and forth, however, the furnace operated well, surface overheating was avoided, and the metal losses were low.

Some of the results on metal losses are tabulated in Table 44.

TABLE 44.—Metal losses in Bureau of Mines laboratory rocking furnace.

Alloy.				Material.	Pouring temperature.	Net loss.
Copper.	Zinc.	Tin.	Lead.			
88.2	11.4			Ingot.....	° C. 1,080	Per ct. 1.05
88.0	12.0	0.3	(b)	Chips.....	1,000	3.00
71.7	28.0	.5	3.0	do.....	1,125	1.60
71.4	28.0	.5	3.0	Ingot.....	1,150	.50
88.0	12.0	3.0	4.0	Chips.....	1,200	1.00
88.0	12.0	3.0	4.0	Scrap and gates...	1,225	.50
88.0	12.0	4.0	6.0	Ingot.....	1,200	.20

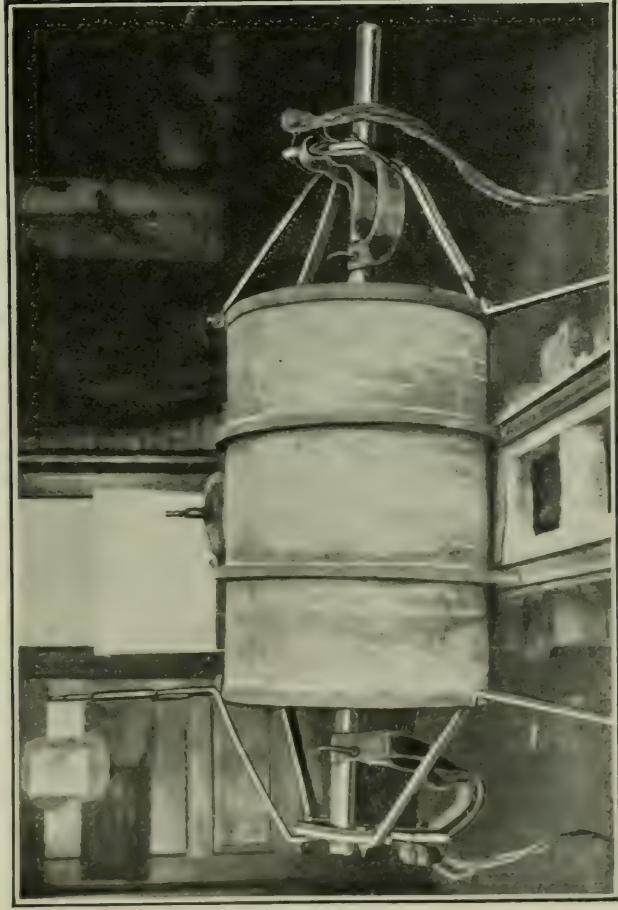
^a The net loss on this alloy when the furnace was not rocked was 6.45 per cent, including some leakage into the flyash hearth.

^b Cu, 9.4 per cent; Pb, 1.5 per cent; Mn, trace (manganese bronze).

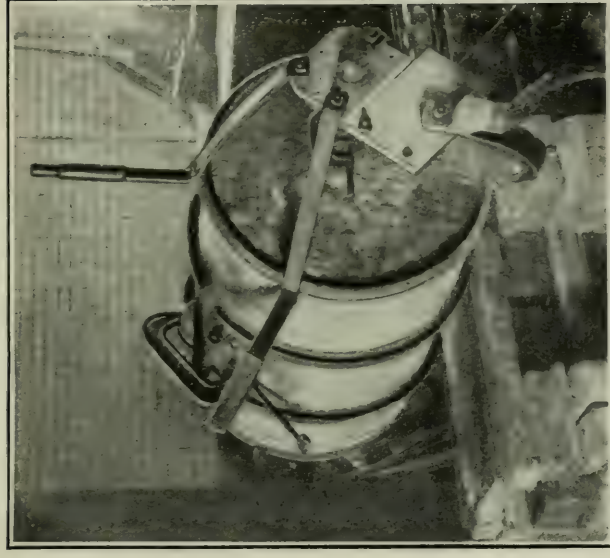
^c The net loss on the same alloy in an oil-fired furnace, crucible practice, was 7.2 per cent, the gross loss 7 per cent in the rocking furnace.

POWER CONSUMPTION.

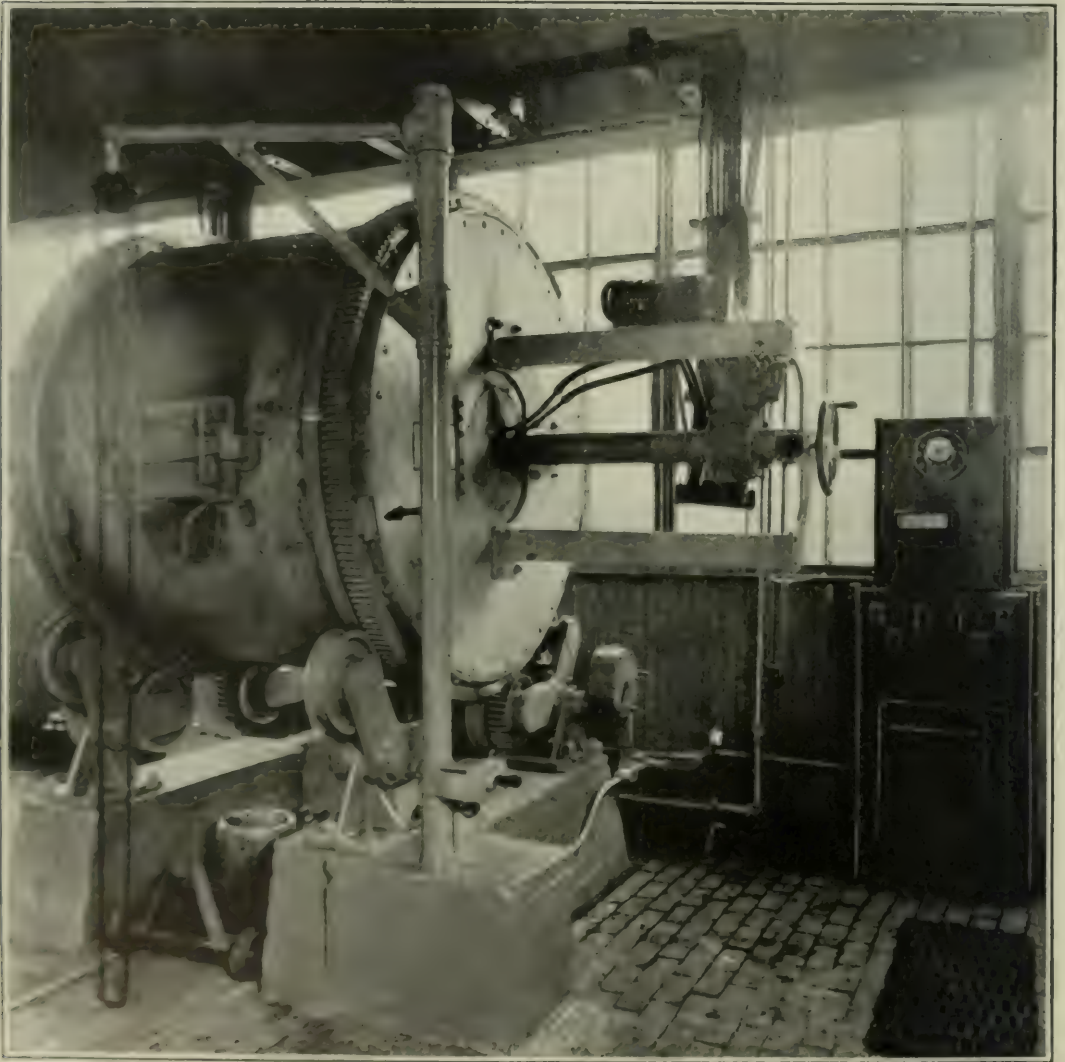
The furnace, working on 125 to 130 pound charges of red brass, poured at 1,200° C., melted five heats, 640 pounds, in five hours, including 1 hour and 10 minutes used in charging and pouring—start-



A LABORATORY ROCKING FURNACE, SIDE VIEW.



B. LABORATORY ROCKING FURNACE, END VIEW.



A ONE-TON DETROIT ROCKING FURNACE WITH OLD-STYLE SUPPORTS.

ing with the furnace cold—by using $136\frac{1}{2}$ kw. h., or at the rate of 430 kw. h. per ton.

On 10-hour operation it should give 10 heats, 1,250 pounds, at the rate of 375 kw. h. per ton, and on 24-hour operation 24 heats, nearly 3 tons, at less than 325 kw. h. per ton. The electrode consumption was at the rate of about 3 pounds per ton.

BUREAU OF MINES EXPERIMENTAL 1,300-POUND ROCKING FURNACE.

The laboratory experiments on a furnace of 125 pounds capacity having indicated that such a furnace might be of value, the cooperation of the Detroit Edison Co. and the Michigan Smelting and Refining Co. was enlisted, and tests on a 1,300-pound furnace were made by the Bureau of Mines at the plant of the latter firm. The first heat was made on May 9, 1917.

The experimental furnaces and the results of the experimental work have been fully described elsewhere³⁵ and need be but briefly summarized here.

The furnace (see Pl. XIV) held 1,300 pounds and was run at 100 to 200 kw., averaging about 165. The arc ran at about 110 to 120 volts, and the furnace had a power factor of about 85. The electrodes were 4-inch diameter, graphite.

The inner lining of the furnace was of corundite brick, back of which was a special heat-insulating brick, with infusorial earth brick next the shell. Handwheels were provided for electrode adjustment, and the rocking motion was automatically controlled by a reversing motor, contactors, and suitable control device.

The furnace was kept stationary after a heat was started until some of the charge had begun to melt; then it was rocked through a small angle, or "safe rock," because by being rocked too far the solid part of the charge would fall on the electrodes and break them. The large furnace required much more care in this respect than the laboratory furnace, as the latter could be rocked through a large angle early in the heat, especially if the material melted was borings or other fine scrap not heavy enough to break the electrodes; in the large furnace even that kind of material would mat together into heavy chunks and would break the electrodes if the furnace were rocked too far too early in the heat. As the charge melted the angle of rocking was gradually increased until by the time that all was melted only the charging door and pouring spout were unwashed

³⁵ Gillett, H. W., and Rhoads, A. E., Melting brass in a rocking electric furnace: Bull. 171, Bureau of Mines, July, 1918, 131 pp.; A rocking electric brass furnace: Jour. Ind. Eng. Chem., vol. 10, 1918, p. 459; Met. Chem. Eng., vol. 18, 1918, p. 583; Met. Ind. (N. Y.), vol. 16, 1918, p. 265,355; Met. Ind. (London), vol. 13, 1918, pp. 102, 116, 132; Foundry, vol. 46, 1918, p. 314; Brass World, vol. 14, 1918, p. 217; Amer. Machinist, vol. 48, 1918, p. 1013.

by the metal. Figure 31 shows the stages in the rocking of a heat. The furnace was set off the horizontal to induce an end-to-end

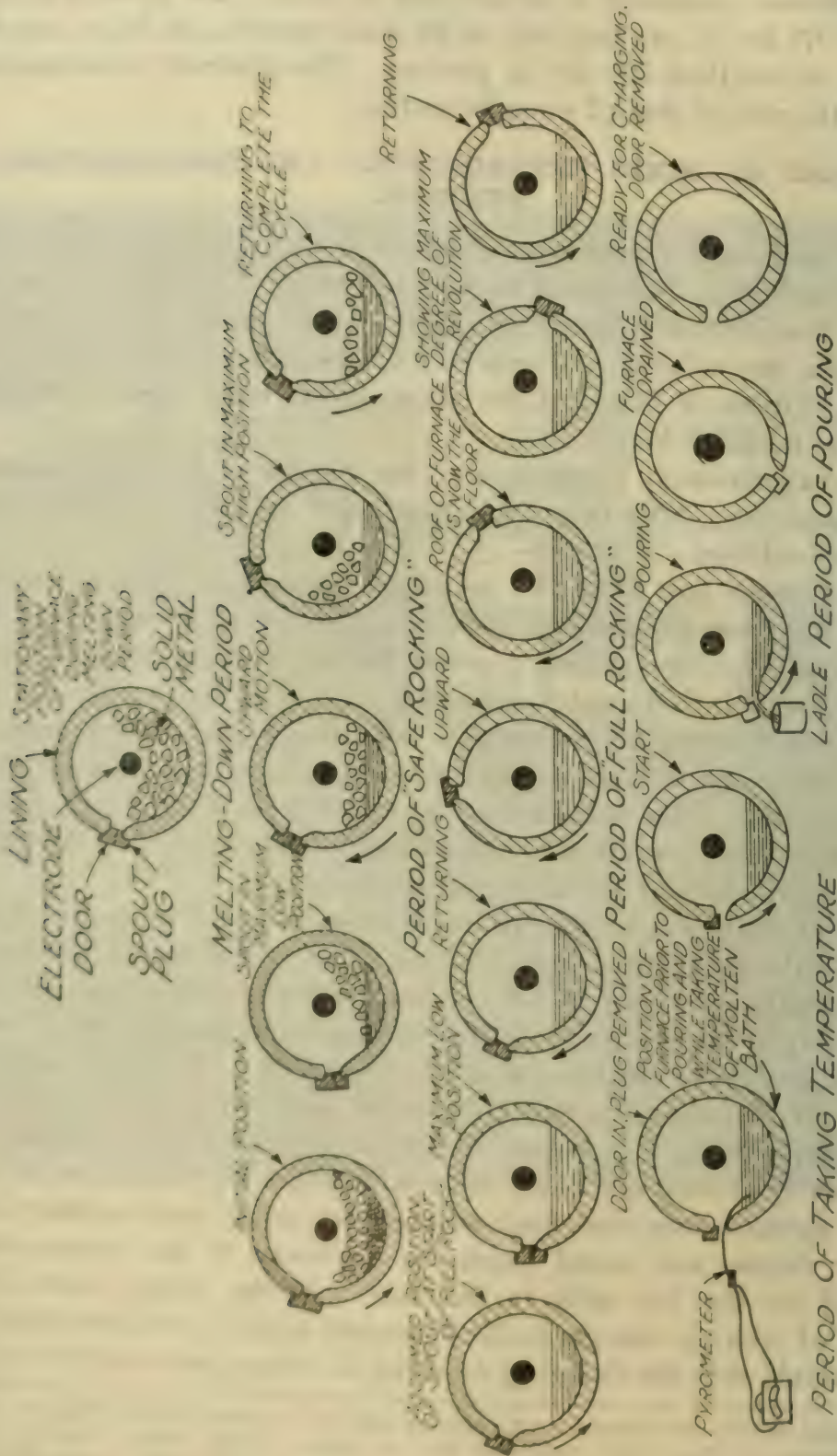


Figure 31.—Stages in the progress of a heat in a rocking furnace.

motion of the metal, as well as a rotary motion, and give more complete stirring.

As the work of the plant where the experimental furnace was set up was the making of ingot of standard composition from scrap charges, the true metal loss was not ascertainable, because of varying amounts of dirt, oil, and other nonmetallic material in the charge. The coke-fired crucibles running on exactly the same charge gave figures with which the electric furnace losses could be compared.

COMPARATIVE METAL LOSSES.

On 102 tons of metal melted in the rocking furnace in strict comparison with the same material charged to the coke fires, the alloys melted running from 90 to 66 per cent copper, 1 to 9 per cent tin, $1\frac{1}{2}$ to $26\frac{1}{2}$ per cent lead, 0 to 30 per cent zinc, the rocking furnace gave 3,626 pounds, or 1.8 per cent more ingot than the coke fires did from the same amount of the same material. Comparative figures on some specific alloys follow in Table 45.

TABLE 45.—*Comparative metal losses in Bureau of Mines 1,300-pound rocking furnace and in coke fires.*

Composition.				Weight charged.	Loss (metal, oil, and dirt), coke fires.	Loss (metal, oil, and dirt), electric.	Saved by electric.
Cu.	Sn.	Pb.	Zn.				
<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Pounds.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>
85	5	5	5	6,576	4.6	3.2	1.4
84	7	8	1	11,600	7.0	3.7	3.3
84	6	10	-----	14,300	2.4	1.8	.6
79	9	10	2	11,790	3.6	2.1	1.4
78	2	10	10	15,840	7.1	3.1	4.0
76	8	13	3	11,805	4.0	2.4	1.6
73	4	20	3	14,392	3.7	2.9	.8
67½	4	26½	2	5,224	3.0	2.4	.6
67	1	2	30	7,200	8.0	5.1	2.9

In melting 75,605 pounds, which contained 266 pounds, or 0.35 per cent oil of leaded bearing bronze, 73,990 pounds good ingot, 106 pounds small ingot or spillings, and 795 pounds metallic in skimmings were obtained, giving on the oil-free basis 1.8 per cent gross loss, 0.6 per cent net loss.

In operating both the laboratory and the 1,300-pound furnace care was taken to keep the furnace door and spout closed and plugged as tightly as possible. The electric furnace gave alloys which analyzed remarkably close to the composition desired. On alloys high in zinc it was especially noticeable that the analyses of the produced showed a much smaller loss of zinc than in the coke fires. For example, a charge aimed to give 67 per cent copper, 30 per cent zinc, and 3 per cent tin and lead and divided between coke fires and the electric furnace gave, on melting in the coke-fired crucibles, an alloy of 68.4 per cent copper and 29.3 per cent zinc; in the electric furnace it gave one of 66.6 per cent copper and 30.4 per cent zinc.

The metal was found to be thoroughly mixed. Analyses of the first ingot from the first ladle and the last ingot from the last ladle of 1,200 pounds heats of an alloy in which 60 per cent copper, 37 per cent zinc, and 3 per cent lead was aimed at, giving the following results:

Heat No.	Per cent copper.	
	First ingot, first ladle.	Last ingot, last ladle.
322	59.76	59.54
23	59.78	59.66

An alloy containing 26 per cent lead was handled with satisfactory results as to freedom from segregation, the metal being more uniform than that from the coke fires.

The metallurgical results were excellent and the reliability and freedom from troubles with refractories appeared good, though the experiments were not continued long enough to get adequate data on the lining life under operating conditions.

RATE OF PRODUCTION AND THERMAL EFFICIENCY.

On 10-hour operation, on red brass poured at 1,150° C., the furnace gave five to six heats, 6,500 to 7,800 pounds, and on a 5-day run, in which 17.2 tons were poured, 5,750 kw. h. were used, or 335 kw. h. per ton.

On 24-hour operation, in a 4-day run, the furnace gave up to 14 heats of 1,300 pounds, or 9 tons per day; 34½ tons were melted in the run, with the use of 8,865 kw. h., or 257 kw. h. per ton. In both these tests the electrode consumption was slightly under 2 pounds per ton. In all these tests the furnace was somewhat handicapped by delays outside the furnace, such as waiting for the crane or for helpers for pouring. Without delays it would be possible to melt 18 heats of 1,350 pounds, or 10 tons, in 24 hours in this size furnace.

Some delay was experienced whenever the charge contained a large proportion of very oily borings, as the vapor is a nonconductor and it is difficult to hold the arc in such an atmosphere. It was therefore necessary to leave the spout unplugged and to wait till the oil had distilled out before starting the arc. The delay could be shortened by charging the borings first so that the oil would be coming off while the rest of the charge was being added, up to, say, 50 per cent oily borings being thus handled with little delay. With larger proportions it was better to leave the door open, charge the borings, and rock the furnace through a small angle to hasten the heating of the borings by the hot walls, and to distill the oil off faster.

In the earlier experiments some difficulty was found in the sticking of the electrodes when melting alloys high in zinc, owing to the condensation of zinc about them. The trouble was not like that found in the unrocked Stassano and Rennerfelt furnaces on similar alloys, and there was no trouble such as with the Rennerfelts on alloys high in lead, even when the alloys contained 26 per cent lead.

Experience in furnace operation showed how to obviate the trouble; either by making the holes through which the electrodes pass sufficiently smooth, as by the use of graphite rings or by using a suitable granular packing about them, and by allowing the electrodes to become a little hotter, reducing the amount of cooling water used, the difficulty was prevented entirely on 24-hour operation.

Similar precautions, coupled with careful cleaning of the electrodes from any deposit at the end of the day, made it possible to operate satisfactorily on alloys high in zinc on 10-hour operation.

It was found both feasible and convenient when making yellow brass from copper, zinc, and scrap to charge the zinc with the rest of the charge at the start instead of "speltering" toward the end of the heat.

The metal melted in the experimental work supervised by the Bureau of Mines all went into the regular output of the Michigan Smelting and Refining Co. After the bureau's tests were finished that firm put the experimental furnace into regular commercial operation.

COMMERCIAL OPERATION OF 1,300-POUND FURNACE.

In over 600 heats of red brass, leaded bearing bronze, cupronickel, etc., in which 725,999 pounds were charged, 697,256 pounds good ingot was obtained, giving a gross loss of 28,743 pounds, or 4 per cent. No deduction is made for spillings, small ingots, metal recoverable from slag, or for oil, dirt, and other nonmetallic on the charge. A similar gross loss figure for a year's operation on the coke fires was given as 7 per cent. The furnace tenders, helpers, and pourers on the crucible furnaces began to draw a bonus for saving metal when the gross metal losses in crucible melting were 6 per cent.

In melting the 363 tons of metal 127,231 kw. h. were used, metered on the secondary side of the transformer, equivalent to 138,500 kw. h. metered on the primary side, or about 380 kw. h. per ton. The furnace was run on one shift, 10 hours or less operation, and was subject to many delays due to outside causes. One furnace operator averaged 380 kw. h. per ton on about 200 tons and a series of less experienced operators 390 kw. h. per ton on about 150 tons. The electrode consumption ran from $3\frac{1}{2}$ to 5 pounds per ton. This furnace was operated until the improved 1-ton rocking furnaces were installed and then dismantled.

The rocking furnace was patented³⁶ and the patents assigned to the Secretary of the Interior as trustee.

Licensing by the Secretary of the Interior was adopted in order to obviate the danger of having some unscrupulous furnace manufacturer with a poorly built furnace advertising his furnace as "advocated by the United States Bureau of Mines" and as far as possible to insure that furnaces made under license are capable of giving the results that the bureau's experiments show should be given by the rocking type of furnace.

DETROIT ROCKING ELECTRIC FURNACE.

The Detroit Electric Furnace Co. was licensed to build and sell rocking furnaces, their furnace embodying improvements on the experimental furnace suggested by the bureau, as well as others indicated by further experience with this type of furnace. The first heat in the first furnace installed by this firm was made on August 27, 1918. On August 1, 1921, 55 furnaces were in actual operation on nonferrous alloys and five more were being installed.

Most of these furnaces are rated at 1-ton capacity, 300 kv. a. Detroit furnaces are shown in Plates XV (p. 213), XVI, XVII, XVIII, and XIX. They are described by St. John.³⁷

The furnaces are lined with corundite brick on the inside, back of this with a layer of fire brick specially chosen for its heat-insulating properties, and on the outside, next the shell, with Sil-o-cel or infusorial-earth brick.

Some furnaces have also been constructed with a two-layer lining, the other of calcined Sil-o-cel brick, the inner of corundite, the whole lining being but 9 inches thick, which increases the capacity of the furnace. The shell is slightly tilted in the large ring gears to induce end-to-end motion of the charge and to increase the stirring action.³⁸ The plug door is entirely removable from the body of the furnace by a small jib crane located near the furnace.

The door is of generous size, and by turning the furnace till the door is uppermost the charge can be put in by a mechanically dumped bucket or similar device. The electrode holders have a long path of travel, so that the electrodes can be drawn completely out of the furnace chamber to avoid breakage while charging. The other

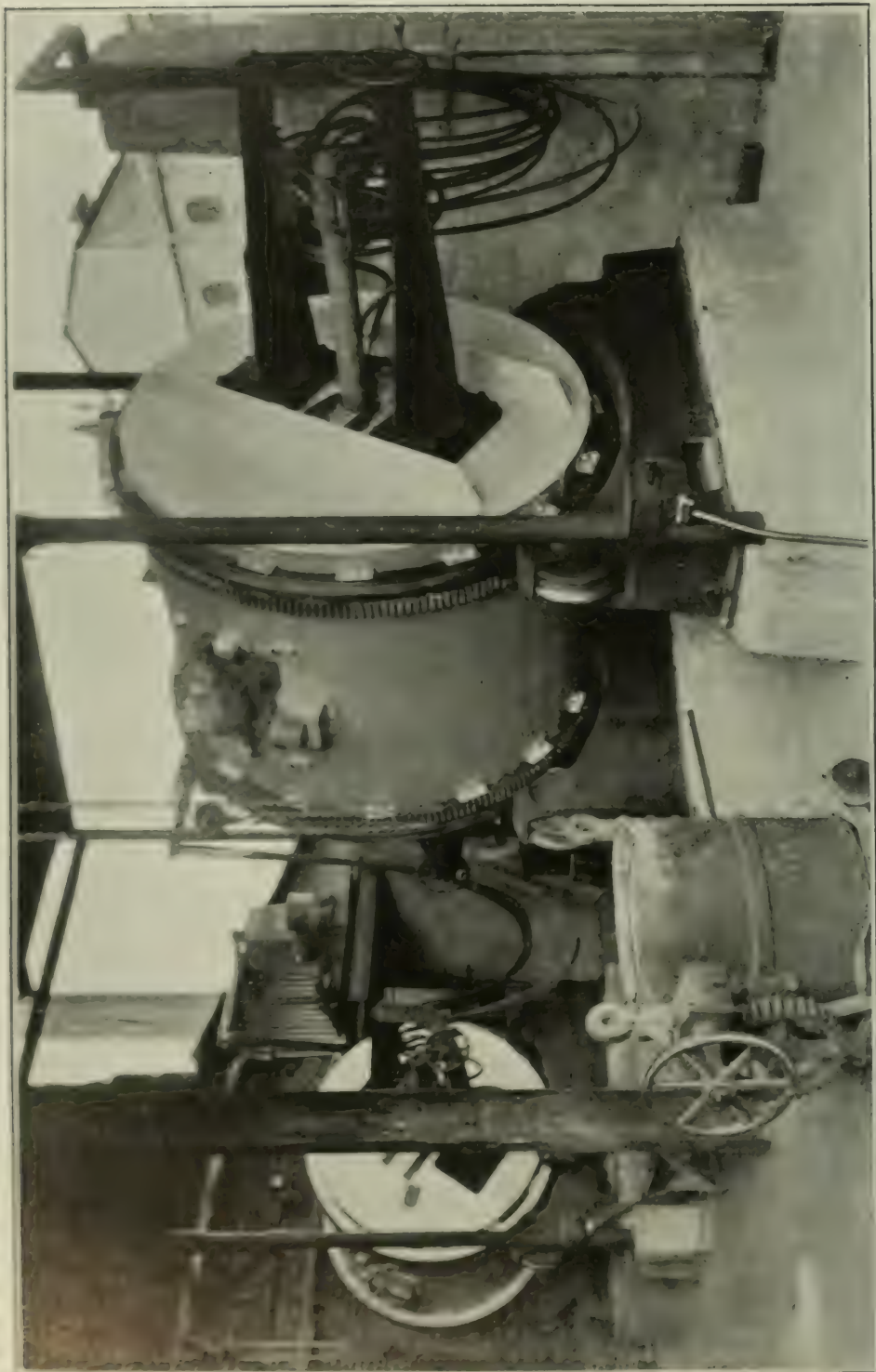
³⁶ Gilbert, H. W., and Lehr, J. M., U. S. Patent 1,201,224, Oct. 10, 1916, application filed Nov. 7, 1915; Gilbert, H. W., U. S. Patent 1,201,225, Oct. 10, 1916, application filed Mar. 21, 1915.

³⁷ St. John, H. M., The Detroit rocking furnaces for melting brass and bronze; *Metal Ind.*, vol. 17, 1919, p. 329; *Metal Ind.*, vol. 18, 1920, p. 211; see also St. John, H. M., Melting nonferrous metals and their alloys in the electric furnace; *Chem. and Met. Eng.*, vol. 22, 1920, p. 148; Yates, R. F., Melting brass electrically; *Sci. Amer.*, vol. 122, 1920, p. 231; Some practical data on operating electric brass furnaces; *Elec. Rev.*, vol. 76, 1920, p. 215.

³⁸ See Gilbert, H. W., U. S. Patent 1,201,225, Oct. 10, 1916; compare also Crosby, E. L., U. S. Patents 1,336,829, Apr. 18, 1920, and 1,367,021, Feb. 1, 1921.



BATTERY OF ONE-TON DETROIT ROCKING FURNACES AT THE PLANT OF THE MICHIGAN SMELTING AND REFINING CO



A ONE-TON AND A HALF-TON DETROIT ROCKING FURNACE AT THE PLANT OF THE OREGON BRASS CO., SHOWING
NEW STYLE SUPPORT.

details are made clear by the photographs. A recent development has been the adaptation of this furnace for pouring direct into molds instead of by a ladle. Plates XVIII and XIX show direct-pouring furnaces in process of erection, some cables, meters, etc., not yet being in place.

In this form the furnace rests on the rollers in the base shown while melting, this form of base having now superseded that shown in Plate XV on the ladle-poured furnace as well. At pouring the furnace is rocked forward till the bar in front engages the sockets in the front of the base, and a lifting screw at the rear is swung into position so that it engages the rear hinge. The motor-actuated screw then rises, lifting the furnace bodily off the rollers and driving gears, so that the furnace is then supported and tilted like all direct-pouring or nose-tilting furnaces. The supporting bar in front is located below the lowest position of the spout during rocking and hence does not interfere with rocking. Data on some of the installations of Detroit rocking furnaces are given below.

FURNACES AT C. B. BOHN FOUNDRY CO.

On a metal loss test on 60:40 brass, poured at 975° to 1,000° C. (1,790° to 1,830° F.), in which heavy scrap and ingot were melted, 14 heats, 28,207 pounds charged, gave 27,743 pounds castings, 48 pounds spillings, and 125 pounds metal recoverable from skimmings, a net loss of 291 pounds, or 1.03 per cent.

Although the furnace was only operated five to seven hours per day during this test, the power consumption averaged 325 kw. h. per ton. The average power input was 210 kw.

During a period when two furnaces were operating, one on two 10-hour shifts, the other partly on one and partly on two shifts, 412,183 pounds of red brass and phosphor bronze were melted with 88,360 kw. h., or 433 kw. h. per ton. The furnaces were run slowly, often waiting for molds, and the time taken in charging, pouring, and waiting between heats was excessive, being longer than the actual heat itself. The actual running time per 1-ton heat averaged about one and one-half hours, while the time spent in charging, pouring, and waiting averaged about two hours per heat, although one-half hour is ample if the demand for metal is sufficient to allow running the furnaces at full speed. Such operation is, of course, a great handicap to any furnace. On 20 tons melted in one furnace during this period the average power consumption was 375 kw. h. per ton. Notwithstanding that the furnaces were not run at their highest efficiency, the melting cost was lower than in the coke fires.

The makers claim that the first furnace installed at this plant made savings in the first 18 months of its operation equivalent to five

times its cost of installation; in this period the furnace paid for itself and for four other furnaces now installed at this plant.

FURNACE AT MICHIGAN SMELTING AND REFINING CO.

On a run in which 356,391 pounds red brass were charged, 344,843 pounds of good ingot were obtained, a gross loss, including oil and dirt, of 12,548 pounds, or 3.5 per cent. Of this charge 173,551 pounds were borings, on which the average loss, when melted alone in coke-fired crucibles, was 7 per cent, or 12,100 pounds.

The 172 tons poured used 52,700 kw. h., or about 310 kw. h. per ton. The furnace was operated for two 10-hour shifts per day; that is, a 20-hour operation.

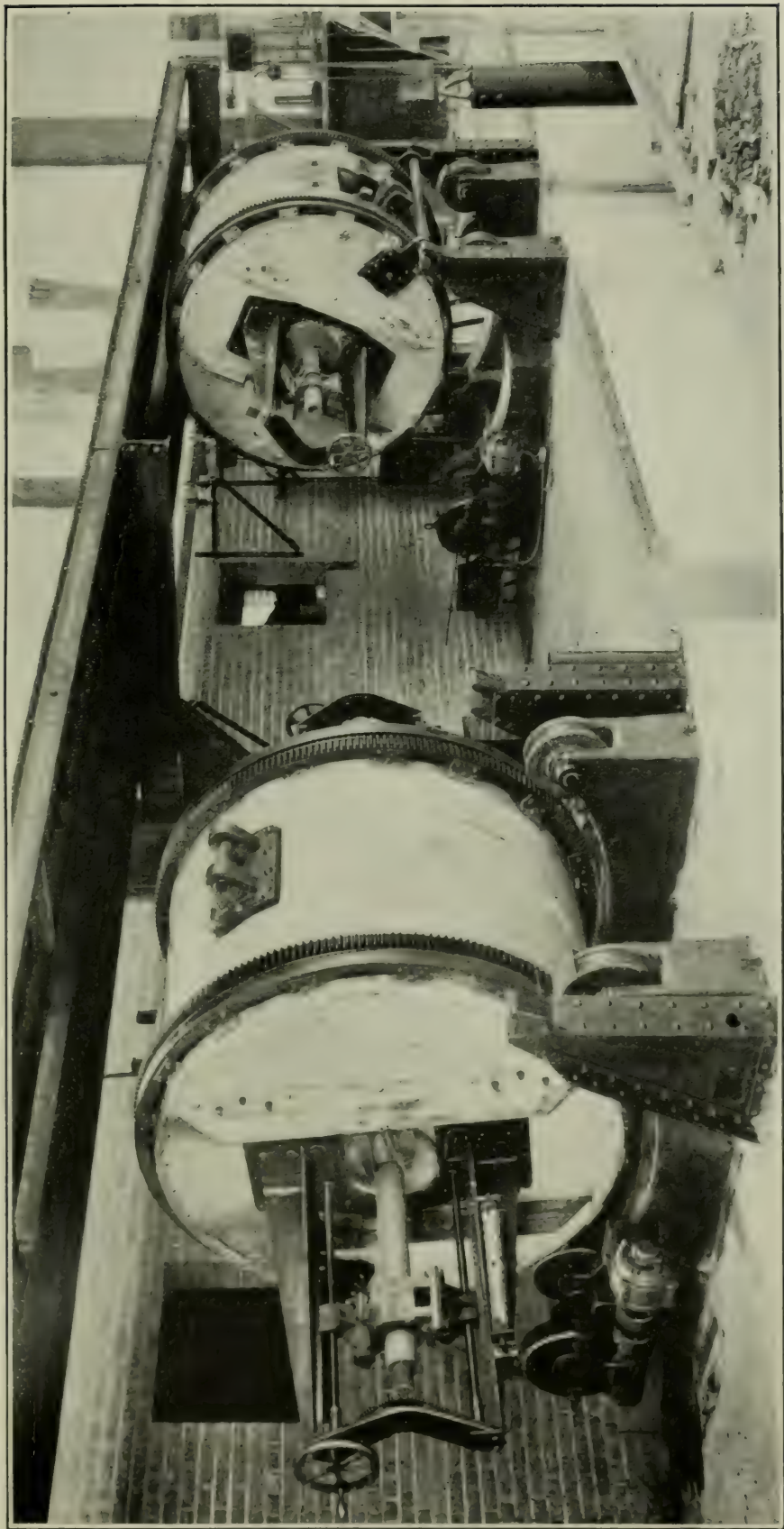
On a run in two furnaces on red brass, two-shift, 20-hour operation, in which 497,565 pounds were charged, 479,272 pounds of good ingot and 3,243 pounds metal recovered from skimmings were obtained, a loss of 15,050 pounds, or 3 per cent, which includes oil, dirt, etc., on the material charged. The 240 tons poured used 81,900 kw. h., or 340 kw. h. per ton. On 6,000 tons melted in rocking furnaces in 1919 at this plant the average power consumption was 364 kw. h. per ton.

The cost department of this firm is said to take the melting cost in the rocking furnace on 20-hour operation at one-half that in the coke fires.

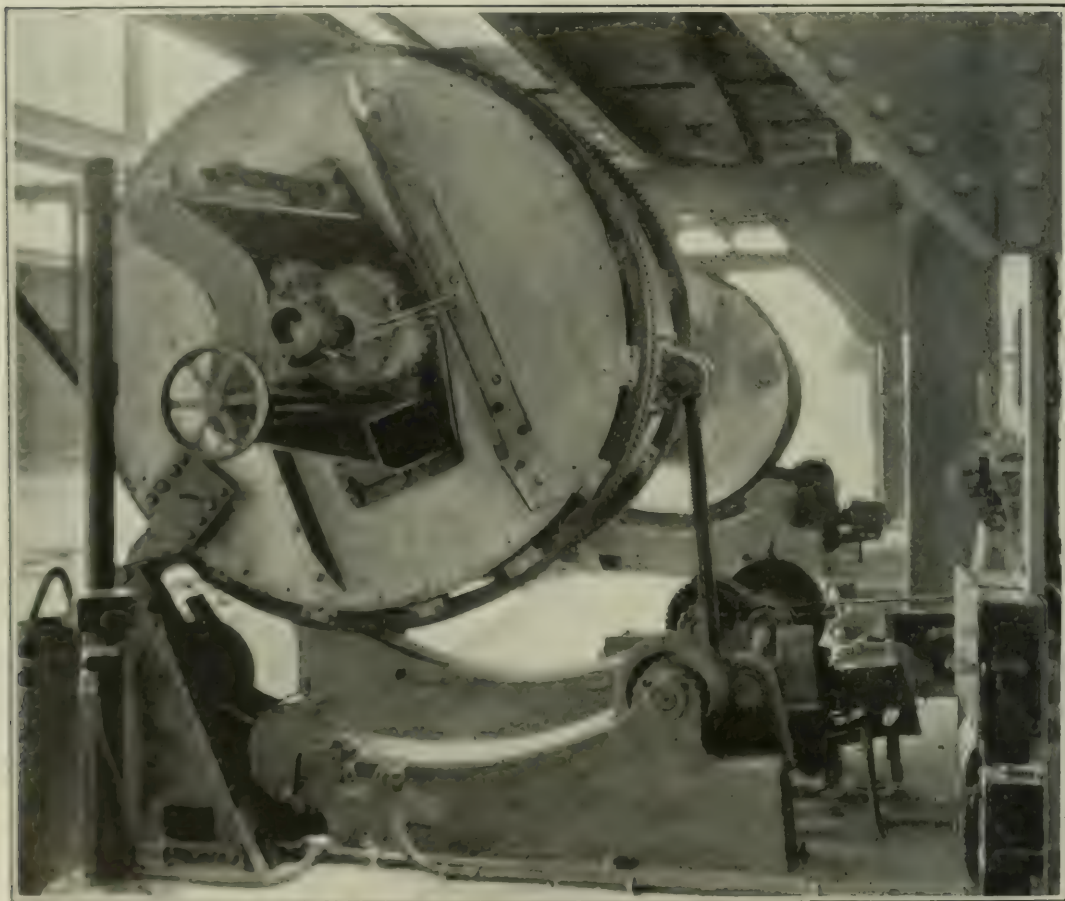
In order to find out whether it were practical to melt a charge of all or practically all oily yellow brass borings, with no admixture of heavy scrap or new metals, a test was run in one of the rocking furnaces of the Michigan Smelting and Refining Co. The borings used contained 3.7 per cent nonmetallic, mostly oil; that is, they were 96.3 per cent metallic. The composition of the brass was approximately 62 per cent copper, 35 per cent zinc, $2\frac{1}{2}$ per cent lead, $\frac{1}{2}$ per cent tin and iron.

Only 1,500 pounds of borings could be charged at the start into the furnace, which holds 2,000 to 2,400 pounds of ordinary charges, on account of the bulkiness of the borings. As the 1,500 pounds of borings carried over 50 pounds of oil and other nonmetallic material, say about 4 gallons of oil, a good deal of oil vapor appeared.

On the first three heats no attempt was made to burn off the oil after charging and before starting the arc, and the spout was not plugged tight at any time during the heat, being left open to allow the oil vapor to escape. The "safe rock" was started after the first 35 to 45 kw. h. of each heat. The furnace was warm at the start from one previous heat, but was not at full running temperature throughout the furnace walls, and therefore the power consumption was higher in the first series of heats.



A ONE-TON DETROIT ROCKING FURNACE, DIRECT-POURING TYPE IN A ROLLING MILL. LEFT, FURNACE IN ROCKING POSITION; RIGHT, FURNACE IN POURING POSITION. PHOTOGRAPHED DURING INSTALLATION; CABLES NOT ATTACHED.



DIRECT-POURING DETROIT ROCKING FURNACE IN POURING POSITION. PHOTOGRAPHED DURING INSTALLATION; CABLES NOT ATTACHED.

TABLE 46.—*Test on all-yellow borings in rocking furnace, spout open throughout run.*

[Elapsed time for three heats: 5 hours and 20 minutes=1 hour and 47 minutes per heat.]

Heat No.	Charged.			Poured.	Average recovery from skimmings.	Gross metallic loss.	Net metallic loss.	In product.	Kw. h. used.
	Metallic in borings.	Ingot.	Total metallic.						
	Pounds.	Pounds.	Pounds.	Pounds.	Pounds.	Pounds.	Pounds.	Per cent.	
1.....	a 1,444½	.....	1,444½	1,253	75½	191½	116	66.0	260
2.....	1,444½	.....	1,444½	1,262	75½	182½	107	66.5	248
3.....	1,444½	40½	1,494	1,302	75½	192	116½	66.9	242
Total.....	.....	.....	4,383	3,817	226½	b 566	c 339½	66.5	d 750

a 1,500 pounds oily borings.

b Equal to 12.9 per cent.

c Equal to 7.7 per cent.

d Average, 395 kw. h. per ton poured.

In the next series the furnace was rocked back and forth during charging and after charging to burn off the oil, the spout was left open until the oil vapor no longer came off in great volume and then was plugged. If the luting blew out it was replaced until the furnace remained tight. Smoky oil vapor continued to come out of cracks in the spout luting and around the electrodes for some time after luting up, but no zinc flames appeared till the metal was almost ready to pour, when very small zinc flames appeared in places around the edges of the charging door.

TABLE 47.—*Test on all-yellow borings in rocking furnace, spout plugged.*

Heat No.	Charged.			Poured.	Average recovery from skimmings.	Gross metallic loss.	Net metallic loss.	In product.	Kw. h. used.
	Metallic in borings.	Ingot.	Total metallic.						
	Pounds.	Pounds.	Pounds.	Pounds.	Pounds.	Pounds.	Pounds.	Per cent.	
4.....	1,444½	42	1,486½	1,361	75½	125½	50	64.0	210
5.....	1,444½	47	1,491½	1,415	75½	76½	1	63.6	200
6.....	1,444½	54	1,498½	1,384	75½	114½	39	63.3	195
7.....	1,444½	34	1,478½	1,372	75½	106½	31	63.4	195
8.....	1,444½	38	1,482½	1,366	75½	116½	41	63.4	200
9.....	1,444½	43	1,487½	1,404	75½	83½	8	63.4	190
10.....	1,444½	.....	1,444½	1,447	75½	2½	a 78	63.8	200
11.....	1,444½	.....	1,444½	1,399	75½	45½	b 30	63.7	210
12.....	1,444½	.....	1,444½	1,374	75½	70½	b 5	n. d.	c 290
13.....	1,444½	.....	1,444½	1,344	75½	100½	25	62.8	190
14.....	1,444½	.....	1,444½	1,319	75½	125½	50	64.6	200
15.....	1,444½	.....	1,444½	1,355	75½	89½	14	64.0	200
16.....	1,444½	.....	1,444½	1,373	75½	71½	b 4	n. d.	d 250
Total.....	.....	.....	19,026½	.....	.....	e 1,123½	f 142	63.8	g 2,730

a Furnace not completely drained on all previous heats.

b Gain.

c Furnace left idle for 7 hours after most of oil had been smoked off, but before charge had begun to melt.

d Four hours between end of heat 15 and start of heat 16. Total elapsed time for 13 heats, deducting idle time in heat 12 and between heats 15 and 16, 33 hours, or 2 hours and 33 minutes per heat.

e Equal to 5.9 per cent.

f Equal to 0.75 per cent.

g Average, 290 kw. h. per ton poured, continuous or 24-hour operation.

As not all the 50 pounds or thereabouts of oil and other nonmetallic materials present in each heat volatilized entirely, but much de-

composed and gave a blanket of soot over the metal in the furnace, much metal was entrained in this soot. The soot and metal shot skimmed off from each heat was not kept separate. In the 16 heats 1,664 pounds of this material was skimmed off, from which 321 pounds of large pieces were hand-picked. The other 1,343 pounds contained 66.6 per cent, or 884 pounds, of recoverable metal, a total of 1,205 pounds or 75½ pounds per heat. The recovered metal thus amounted to about 5 per cent of the charge.

The net loss, obtained by weighing the empty ladles before pouring, skimming, and weighing the ladle plus metal, of 7½ per cent in the first series and only three-fourths of 1 per cent does not check well with that calculated on the analysis, which figures out to about 9 per cent in the first series and 2½ per cent in the second. All the figures, however, tend to show that the net loss is considerable when the spout is left open throughout the heat, and not very high, for this class of material, when the spout is plugged tightly as soon as the oil is sufficiently distilled off to allow it, but before the zinc begins to be volatilized.

The furnace runs much more slowly, and gives a much lower production when operated by not running the arc till the oil is smoked off than it would if the oil were not present and the arc could be run from the start.

If the amount of borings is small enough that the heat of the furnace walls can distill off all the oil so quickly that little of it decomposes inside the furnace to form soot, production is not much cut down, as the borings can be charged first and the oil will come off while the rest of the charge is being put in. Mechanical charging is desirable in such a case. The outrush of burning-oil vapor makes hand charging difficult, though by pointing the spout upward and throwing the charge in with a shovel, the workmen can keep out of the flame. If the oil is distilled out of instead of decomposed within the furnace the entrainment of shot metal by the blanket of soot is prevented, and the percentage of charge that has to go through a recovery process is much reduced.

It is possible that much better results would be obtained on charges of all yellow, oily borings if 1,000 pounds only were charged at a time in a 1-ton furnace. Red borings are not so bulky, do not as a rule hold so much oil as yellow ones, and, because of their greater compactness, are heated more quickly to the point where the oil will distill out, so that charges of all red borings, even though quite oily, are not troublesome. If 500 pounds were charged and melted, and then 500 pounds more charged and melted, followed by another or perhaps two more such charges, the escape of oil might be hastened. As it is generally poor policy, however, to charge a large amount of cold metal into a small mass of hot metal on account of the danger of

freezing the whole charge, and as it takes time to open and close the furnace, the use of 1,000-pound or even smaller charges might be the best way to handle charges of all oily yellow borings in the 1-ton furnace.

Melting this oily material alone is about the most disagreeable work the brass melter ever has to do. The usual method is to use a pit coke-fired crucible furnace, and to poke the charge continually in order to keep the soot from preventing the coalescence of the globules formed as the borings melt. The labor cost for melting is high, as a furnace tender can attend only to few pots.

Such poking or rabbling is difficult on any large electric furnace taking a large charge on account of the oil flame. All oily yellow borings have been satisfactorily melted in the small Ajax-Wyatt induction furnace, by adding about 25 pounds every 10 minutes, and poking them in, but this method also makes the labor cost high.

According to the technical superintendent³⁹ of the Michigan Smelting and Refining Co., neither the rocking furnaces nor the Baily furnaces, of which four of each are installed at that plant, can handle as well as the coke fires charges of 100 per cent oily yellow borings, the former because of lowered production from difficulties caused by the oil and the latter because of low production and the necessity of having a man stand in front of the furnace and rabble the charge continually. Such charges therefore are still run in the coke fires. Of the total output of brass and bronze in that plant about 60 per cent, late in 1919, was being melted in the four rocking furnaces, about 30 per cent in the coke fires, and about 10 per cent in the four Baily furnaces.

FURNACES AT DETROIT COPPER AND BRASS ROLLING MILLS.

In a test on yellow brass 61½ per cent copper, 36 per cent zinc, 2½ per cent lead, at the Detroit Copper and Brass Rolling Mills, in 9-hour operation, 14 heats of 1 ton each required 4,085 kw. h., or about 290 kw. h. per ton. On 16-hour, 2-shift operation, 18 heats required 4,500 kw. h., or 250 kw. h. per ton. On the test runs the metal loss, on yellow brass, made up of fairly heavy scrap and new metals (zinc charged at the start), ran from 0.5 to 0.6 per cent.

According to the metallurgist of this firm, in regular operation 10 heats are usually obtained in 16-hour operation, two 8-hour shifts. The power consumption averages 250 kw. h. per ton or less, and the metal loss runs under 1 per cent. The total electrode consumption is about 3¾ pounds per ton. The metal is said to be mixed with absolute uniformity, no greater difference in composition between the first and last metal poured being found than between duplicate analyses of the same sample. That is, within the limits of analytical er-

³⁹ Private communication, October, 1919.

ror the mixing is perfect. The metal is poured direct from the furnace to the molds. The first furnace, installed in an inconvenient location and under rather unfavorable conditions, when operated entirely by a negro crew, gave approximately the same labor costs as on the coke furnaces. With a battery of mechanically charged furnaces it is expected that the labor cost will be materially reduced.

On another recent 5½-day test at this plant 34 tons were melted, 6 heats of 1 ton each being made per 9-hour day, the average power consumption being about 275 kw. h. per ton, and the net metal loss 0.90 per cent on a charge of half new metal, half scrap.

The original furnace at this plant has been altered to the direct pouring type, and when the furnaces that are now being installed are in operation this firm will have eight 1-ton direct-pouring Detroit furnaces.⁴⁰

RESULTS AT CHASE METAL WORKS.

At the Chase Metal Works, operating two furnaces on 60:40 brass, poured at 2,000° F. (1,100° C.) or above, one furnace was run one 8-hour shift only, and for 170 1-ton heats averaged 6,800 pounds output per 8 hours, the average power consumption being 280 kw. h. per ton.

The other furnace, run two 8-hour shifts, averaged for 100 1-ton heats 16,500 pounds output; that is, it melted 8 to 9 tons in 16 hours. The actual melting time per heat was only 56 minutes, so that by speeding up the pouring and charging the output could be increased materially. The average power consumption was 225 kw. h. per ton.

For 127 heats in both furnaces, the average metal loss was 1 per cent.

In the melting of 500 tons of 60:40 brass in four furnaces, this plant later cut the actual melting time to about 52 minutes per heat. The average power consumption was about 240 kw. h. per ton and the net metal loss 1.02 per cent, the charge being one-half new copper and zinc, the other half heavy scrap and briquetted borings. Still later figures on 60:40, 24-hour operation, showed on 55 heats of all clean metal an average of 225 kw. h. per ton and an output of 16½ tons per day, with 33 consecutive heats running at 210 kw. h. per ton and 18½ tons output, while on 79 heats which contained about 25 per cent of oily borings the average was 265 kw. h. per ton and the output 12½ tons. Gross losses ran from 1.85 per cent on clean metal to 4.27 per cent on dirty, oily charges. Net losses were not determined.

⁴⁰ See Freeman, F. L., *Direct pouring in a modern brass plant*: Iron Age, vol. 108, 1921, p. 68.

FURNACE AT CLEVELAND BRASS AND COPPER ROLLING MILLS.

On charges of 1,000 pounds heavy scrap, 900 pounds light scrap, the alloy melted being 60 per cent copper, $37\frac{1}{2}$ per cent zinc, $2\frac{1}{2}$ per cent lead, a $5\frac{1}{2}$ -day run, working 8 hours per day, at the Cleveland Brass and Copper Rolling Mills, showed a production of 6 heats or 5.7 tons per day, a power consumption of about 220 kw. h. per ton, and a gross metal loss of 1 per cent. The electrode consumption was 2.4 pounds per ton.

METAL LOSS COMPARED WITH THAT IN OIL FURNACE.

An interesting comparison was made by the Ford Motor Co. between the composition of the metal produced by the rocking furnace and an open-flame oil furnace, the same charge being fed to both furnaces. The alloy desired was a bearing bronze of about 87 per cent copper, $8\frac{1}{4}$ per cent tin, $3\frac{1}{2}$ per cent zinc, $1\frac{1}{4}$ per cent lead with a small amount of phosphorus. The analysis for zinc and lead showed the following results:

TABLE 48.—Comparative analysis of products from similar charges melted in open-flame oil furnaces and in rocking electric furnaces.

Open-flame oil furnace.		Electric rocking furnace.	
Zinc.	Lead.	Zinc.	Lead.
<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
3.08	1.73	3.71	1.30
3.08	1.85	3.84	1.70
1.32	1.85	3.82	1.77
3.14	0.99	3.59	1.73
1.55	1.83	3.59	1.73
2.62	1.28	4.08	1.85
2.38	1.65	4.01	1.56
3.26	1.31	4.09	1.56
1.21	1.47	4.71	1.73
2.56	1.42	4.18	1.48
3.12	1.59	4.71	1.93
1.16	1.47	3.84	1.60
2.94	1.91	4.38	1.96
3.37	1.39	4.35	1.74
2.11	1.39	6.63	1.56
		4.05	1.47
		4.25	1.43
<i>a</i> 2.53	<i>a</i> 1.54	<i>b</i> 4.05	<i>b</i> 1.65

a Average—open-flame oil furnace—zinc, 2.53 per cent; lead, 1.54 per cent; total, 4.07 per cent.

b Average—electric rocking furnace—zinc, 4.05 per cent; lead 1.65 per cent; total, 5.70 per cent.

An occasional variation may be due to variations in the individual charges, though all charges to both furnaces were calculated to be the same. The lowest zinc content in the electrically melted metal was higher than the highest from the open-flame oil furnace. As the electrically melted alloy contained in 100 pounds 94.3 pounds of copper and tin and 5.7 per cent lead and zinc, the metal obtained in the oil furnace from the same amount of charge would

contain 94.3 pounds copper and tin and 3.95 pounds lead and zinc $\frac{3.95}{598.2} = 4.08$ per cent, the metal melted by oil gave 94.3 and 3.95, or 98.25 pounds, from the same weight of charge that gave 100 pounds to the electric; that is, the metal loss, calculated from the average analysis, is 1.75 per cent more in the open-flame oil furnace than in the electric.

In another plant which also operated another make of open-flame oil furnace and a rocking furnace on this same alloy, with a charge that contained 25 per cent borings and grindings, the gross metal loss in the oil furnace was found on test to be 2.69 per cent and that in the rocking furnace 0.94 per cent; the rocking furnace thus saved again 1.75 per cent over the open-flame oil furnace.

The saving found in one plant, calculated by analysis, and that found in another plant, determined by weighing, is thus seen to be exactly the same on the same alloy.

After the test cited above showed that the Ford Motor Co.'s electric furnace was giving a product higher in zinc than was aimed at owing to its lower loss, the charge to the electric furnace was altered to compensate for this difference, and the following analyses on 13 consecutive heats shows the uniformity of the product from heat to heat:

TABLE 49. — Analysis of 13 consecutive heats from the rocking furnace.

Copper.	Tin.	Lead.	Zinc.	Phosphorus.
86.90	8.35	1.63	3.04	0.015
87.18	8.43	1.09	3.28	.020
86.68	8.47	1.37	3.56	.020
87.24	8.36	1.26	3.10	.020
86.84	8.30	1.21	3.73	.014
86.94	8.10	1.04	3.91	.014
87.80	7.64	1.36	3.20	.020
87.16	8.27	1.30	3.26	.014
86.96	8.27	1.33	3.43	.010
86.82	7.98	1.21	3.96	.025
87.30	8.27	1.25	3.27	.014
87.12	8.27	1.23	3.36	.016
86.80	8.39	1.21	3.39	.013
<i>a</i> 87.06	<i>a</i> 8.24	<i>a</i> 1.27	<i>a</i> 3.42	<i>a</i> .0165
MAXIMUM DEVIATIONS.				
—0.37	—0.60	—0.23	—0.38	.....
+ .74	+ .35	+ .34	+ .54	.....

a Average

FURNACE AT PLANT OF ALUMINUM MANUFACTURERS, INC.

On 10 heats, 2,125 pounds per heat, of phosphor bronze, poured at 2,250 to 2,300° F. (1,230 to 1,260° C.), a much higher temperature than the average plant requires, the average power consumption in a rocking furnace at one of the plants of Aluminum Manufacturers,

Inc., was 330 kw. h. per ton, the furnace being operated 9 hours per day. The charge was poured in 8 ladles, each holding 265 pounds. It took an average of 25 minutes to pour, and 25 minutes to charge a heat. On account of the long time spent in charging and pouring, only 4 heats, $4\frac{1}{4}$ tons, were made in 9 hours. This firm now has two rocking furnaces in operation.

FURNACE AT ROME WIRE CO.

It is claimed by the users that the 1-ton furnace at the Rome Wire Co., melting cabbaged copper wire and scrap copper into wire bar, operating 10 hours per day, produced 100 per cent conductivity, Mathiesen scale, metal at 280 kw. h. per ton with an output of 6 tons per day. The furnace requires expert operation to give as good a performance as this on copper. This firm has discontinued that part of their manufacturing work for which they were using the furnace, so that this furnace is no longer in use.

FURNACE AT PLANT OF MICHIGAN LUBRICATOR CO.

A time analysis on 18 heats of brass containing 73 per cent copper, 18 per cent zinc, 4 per cent tin, 5 per cent lead, melted in a rocking furnace at the plant of the Michigan Lubricator Co., showed that the average time used in a heat for the different operations was as follows:

	Minutes.	Remarks.
Opening furnace door-----	2	Metal is poured with charging door in.
Cleaning out dross and slag-----	$2\frac{1}{2}$	
Charging-----	$11\frac{1}{2}$	
Rocking—no arc on-----	$8\frac{1}{2}$	This to drive out oil as charges contained oily borings.
Clearing charge away from electrodes-----	$2\frac{1}{2}$	Rocking to drive out oil may bring the charge so close to the electrodes that there is danger of overheating before rocking is started, so any metal lying too close to the arc is pushed away.
Closing and luting door-----	$2\frac{1}{2}$	
Running arc—furnace not rocked-----	$27\frac{1}{2}$	Average power input to arc about 240 kw. while it is running.
Running arc—furnace rocked-----	$62\frac{1}{2}$	
Pouring-----	28	
Adjusting electrodes and all furnace maintenance-----	6	Included time spent at end of day taking out and cleaning electrodes to prevent sticking, as well as taking a fresh grip on electrodes with holders, oiling bearings, and all other furnace maintenance.
Total, 2 hours $33\frac{1}{2}$ minutes.		

It thus takes 10 hours for 4 heats, 2,040 pounds per heat, poured at about $1,100^{\circ}$ C. When the charge does not contain oily borings, it does not have to be left with the arc off for oil to smoke out, does

not have to be cleared away from the electrodes, the arc holds better than it does in the atmosphere of oil vapor so that a higher kilowatt-hour input can be held; there is no blanket of soot on top of the metal to slow up the absorption of heat, therefore 5 heats can be made in $9\frac{1}{2}$ hours. A sixth heat could be made by speeding up the pouring time. On a 4-day run, 20 heats, the power consumption was 315 kw. h. per ton; on another 4-day run, 16 heats, with oily borings present, so that only 4 heats per day were made, the power consumption averaged 350 per ton. The last heats of the day, under the condition that would hold in 24-hour operation, came out at 300 to 315 kw. h. per ton when borings were used, and 260 when they were not used. On another run on the 18 per cent zinc alloy, melting 37 tons in 7 working days, 5 heats in 9 hours, the power consumption was about 315 kw. h. per ton, the electrode consumption 3.2 pounds per ton, and the gross metal loss 2.5 per cent on a charge of 45 per cent gates, scrap, lead, and copper, and 55 per cent borings. The average nonmetallic in the charge was 1.6 per cent, making the net metallic loss 0.9 per cent.

FURNACE AT SHERWOOD BRASS FOUNDRY.

On a 50-ton run of red brass, 85 per cent copper, 5 per cent tin, 5 per cent zinc, 5 per cent lead, in one of the 1-ton rocking furnaces at the Sherwood Brass Foundry, the charge being mostly ingots and gates, the average output was $4\frac{2}{3}$ tons in 9 hours, 20 minutes, or 1,000 pounds per hour, elapsed time, including all delays.

The power consumption was about 345 kw. h. per ton. In melting 31 tons, 170 pounds electrodes were actually consumed and 34 pounds broken and discarded, total 204 pounds, or 4 pounds per ton.

The other 1-ton rocking furnace at this plant, on 17 tons of leaded bronze (82 per cent copper, 10 per cent tin, 8 per cent lead, trace phosphorus), from a charge containing 20 per cent borings, showed an output of 825 pounds per hour, elapsed time, including a good deal of waiting for molds, and used about 330 kw. h. per ton. The total electrode consumption was 4.1 pounds per ton. On 24 tons, partly of this alloy and partly of red brass, the output was 890 pounds per hour, the power consumption 330 kw. h. per ton, and the electrode consumption 5.1 pounds per ton. A third furnace has since been installed.

FURNACE AT PLANT OF DENNY-RINE CO.

A 1-ton rocking furnace operated in 1919 at the plant of the Denny-Rine Co., Chicago, making ingot, on 24-hour operation, on an alloy of 83 per cent copper, 3 per cent tin, 4 per cent lead, 10 per cent zinc, made up of bulky scrap and 30 per cent oily yellow borings, the charge being so bulky that only 1,600 pounds could be charged

into the 1-ton furnace, gave 20 heats, or 16 tons, in 24 hours, at about 270 kw. h. per ton, with a gross metal loss of 3.6 per cent on a charge containing 2.9 per cent of oil, dirt, and other nonmetallic, or 0.7 per cent net metal loss.

On 24-hour operation on 2,200-pound charges of all red brass borings, 21 to 22 tons were produced in 24 hours, at about 240 kw. h. per ton. The electrode consumption was $2\frac{1}{4}$ pounds per ton on 24-hour operation and $3\frac{1}{2}$ pounds per ton on single-shift operation.

During the period February 1 to September 1, 1919, it is said that the power consumption per ton of metal shipped from this plant was 290 kw. h. per ton. This period included both 24-hour and 1-hour shift operation. The lining life was 600 heats on intermittent operation. This company sold its plant to the Hills-McCanna Co., which now operates the 500-pound furnace formerly used by the Denny-Rine Co. The furnace used by the Denny-Rine Co. is now the property of the Parrish-Pool Co., of Cleveland, which also operates two other 1-ton Detroit furnaces.

A test on leaded bearing bronze made in the Denny-Rine Co.'s furnace shows how lead is absorbed by a hearth until the hearth becomes saturated with it, and also shows the uniformity of the alloy produced by the rocking furnace.

TABLE 50.—*Analysis of first and last metal poured from rocking furnace melting alloys high in lead.*

Heat No.		Cu.	Sn.	Pb.	Appar- ent metal loss—no correc- tion for oil or dirt.
		<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
1	{ First ingot from first ladle.....	72.73	4.97	21.02	8.0
	{ Last ingot from last ladle.....	72.12	4.88	20.97	
2	{ First ingot from first ladle.....	68.89	4.86	23.19	5.85
	{ Last ingot from last ladle.....	69.09	4.47	22.96	
3	{ First ingot from first ladle.....	66.51	4.24	25.49	3.5
	{ Last ingot from last ladle.....	67.15	4.30	25.28	
4	{ First ingot from first ladle.....	67.07	4.30	25.02	2.6
	{ Last ingot from last ladle.....	66.01	4.47	25.87	

FURNACE AT GENERAL ALUMINUM AND BRASS MANUFACTURING CO.

On a test of red brass 85 per cent copper, 5 per cent each of lead, tin, and zinc (38 per cent new metal and ingots, 38 per cent foundry scrap, 24 per cent borings), 34 tons were melted in 60 working hours. Six 1-ton heats were made in 9 hours and 7 in 10 hours. The weight of charge was 68,404 pounds and 68,101 were poured, a gross loss of 303 pounds or 0.44 per cent. The daily gross loss varied from 0.3 per cent to 0.7 per cent. The average electrode consumption was 3.5 pounds per ton. About 9,880 kw. h. were used, an average of

about 290 kw. h. per ton. The average pouring temperature was 1,140° C. (2,085° F.). The power consumption at the end of a day's run was about 250 kw. h. per 1-ton heat. A second furnace is now in use by this plant.

FURNACE AT BRIDGEPORT BRASS CO.

A Detroit furnace used at the Bridgeport Brass Co., operating on pure copper and copper-tin alloys, had some trouble from short life of the refractory lining, but a recent communication ⁴¹ from this firm says: "We have recently been getting very satisfactory results as we have largely remedied the lining troubles that we previously had."

FURNACE AT WHEELER CONDENSER AND ENGINEERING CO.

This furnace was at first handicapped by the line voltage falling lower than was expected, with the result that the furnace could take only about 200 kw. Production was retarded and the power consumption raised. On 150 tons of 60:40 brass, 10-hour operation, with a good many days when the furnace was not run owing to troubles with the power supply, and when as a result unusual preheating was involved, the power consumption ran something under 400 kw. h. per ton, and the gross metal loss was 0.91 per cent. The charges were practically all light scrap and each contained 100 pounds of recovered concentrates which carried some nonmetallic.

On 25 tons, melted later, of 60:40 alloy, 10-hour operation, a Monday morning preheat being included, the power consumption was about 250 kw. h. per ton. In a 94-hour continuous run, melting 37 tons of copper, the gross loss was 0.34 per cent, and the power consumption was about 375 kw. h. per ton. All these runs were handicapped by the low power input.

FURNACE AT WHITE AND BROTHER.

On the first 97 tons, both red and yellow, 10-hour operation, the power consumption was around 350 kw. h. per ton. The latter part of the run gave around 300 kw. h. per ton. If given in terms of the furnace kw.-h. meter all the power consumption figures on the Detroit rocking furnaces cited in this report have been corrected to include the losses in transformers and secondary leads in order to include all the power used.

The power factor of these rocking furnace installations including transformers is usually better than 80, though McMicken ⁴² cites one installation with an over-all power factor of but 72.

Prices of the Detroit rocking furnace, quoted February 24, 1920, east of the Rockies, are f. o. b. Detroit, as follows: 500-pound size, \$6,500; 1,000-pound size, \$8,500; 1-ton size, \$11,500. Automatic

⁴¹ Webster, W. R., personal communication, Aug. 24, 1921.

⁴² M-Micken, A. C., *Elec. World*, vol. 75, 1920, p. 1251.

electrode control costs about \$750 additional and a nose-tilting device for the 1-ton furnace costs \$1,250 additional.

These figures include transformer, reactance, oil-switch, and its remote control operating device, switchboard complete with watt-meter and watthour-meter, contactors, rocking motor, worm-gear reduction drive, rocking-control device, etc. Hyatt roller bearings are supplied on all principal bearings.

LIFE OF LINING IN THE ROCKING FURNACE.

The general average of the life of the lining in the 1-ton rocking furnace is given as about 350 heats though 600 to 800 heats are not uncommon. One plant, pouring at about 1,250° C. (2,275° F.), has obtained only about 125 heats, in one case getting only 25. Oddly enough the brick used in the lining that ran but 25 heats was from the same shipment as a lining that ran 737 heats in another 1-ton furnace at another plant.

The cost of the inner course of corundite brick, which is all that need normally be replaced when relining is done, is given (Mar. 1, 1920) as about \$100, and the labor for relining about \$50. Graphite electrodes cost about 25 cents per pound.

PERFORMANCE OF SMALLER SIZES OF ROCKING FURNACE.

Only scanty data are available on the performance of the smaller sizes. The 1,000-pound furnace at the Oregon Brass Works, operated to average 5 heats, or 2½ tons in 8 hours, gave an average power consumption of 350 kw. h. per ton on 60 heats of red brass, gun metal, and leaded bronze. This size has not been operated on 24-hour service, but the figures for the last heats of the day indicate that it would run at about 250 kw. h. per ton.

The 500-pound furnace at the Hills McCanna Co., operated to give four heats, or 1 ton in 8 hours, used about 385 kw. h. per ton on red brass. On 14 heats, the furnace being operated only for 2 or 3 heats on most of the days, the power used was 425 kw. h. per ton. From the last heats of the day, it is indicated that this size would take about 300 kw. h. per ton on 24-hour operation. According to later data,⁴³ when operated to give 6 heats (1½ tons) in 9 hours, the furnace takes around 315 kw. h. per ton, measured on the secondary side of the transformer or, say, about 340, measured on the primary. By cutting down the delays between heats, 7 heats, 1½ tons, can be made in 9 hours, and the primary power consumption would be about 325 kw. h. per ton. On 24-hour operation, it appears from the last heats of the day, the power consumption should fall to about 275 kw. h. per ton.

⁴³ Diller, H. E., Adapt ingot foundry to castings, *Foundry*, vol. 48, 1920, p. 503.

In May and June, 1920, the furnace being operated to give from 2 to 6 heats a day, averaging about 4, the average output was 346 pounds per hour, at 374 kw. h. per ton, measured on the secondary, that is, about 400 on the primary. The Chapman Valve Manufacturing Co., Indian Orchard, Mass., is installing a furnace like the regular 500-pound size, but with a thinner lining, so as to hold 750 pounds of metal, and provided with a 125-kw. transformer.

ROCKING FURNACE USED IN PREPARATION OF ALUMINUM STEEL AND GRAY IRON.

The Michigan Steel Castings Co. installed a 1-ton rocking furnace for use as a mixer in making up an experimental series of alloys consisting of a low-carbon steel containing 12 to 20 per cent aluminum and 0 to 1 per cent titanium. It was hoped that such alloys might be useful where a material resistant to oxidation at high temperatures is required.

The furnace was operated intermittently; for example, the cold furnace would be raised to a red heat by the use of about 240 kw. h., 200 pounds aluminum charged, melted, and held by the use of 50 kw. h. till the steel was ready to add, then 700 to 750 pounds of molten steel from a Heroult furnace was added, 40 pounds ferro-titanium charged, and the furnace rocked 15 to 20 minutes, using 75 to 100 kw. h. before pouring the resultant alloy.

The furnace was said to give thoroughly mixed metal of uniform analysis, and to allow controlling the pouring temperature, about 2,900° F. (1,600° C.) satisfactorily. The ordinary corundite lining used was not attacked in the 25 experimental heats run; instead there was slowly built up an accretion of slag or dross, which, on being chipped off, left the lining underneath in good condition.

In the casting and use of these alloys some difficulties were found which required further experimental work on the properties of the alloys themselves. No commercial use therefore has been made of the furnace for this purpose.

The Homestead Valve Mfg. Co., Homestead, Pa., has installed a 1-ton Detroit furnace with automatic electrode control to melt gray iron and semisteel. Another 1-ton furnace for the same purpose is being installed by the Russell Wheel and Foundry Co., Detroit, Mich.

According to tests on melting gray iron, it appears that the furnace will produce about 5 tons in a 10-hour day, at around 500 kw. h. per ton. Tensile tests of metal of around 2.75 per cent C, 1.50 to 1.70 per cent Si, 0.50 per cent Mn, 0.06 per cent S, 0.45 per cent P gave about 42,000 pounds per square inch. As high as 70 per cent borings and turnings were successfully used.

DETROIT FURNACE MELTING ALUMINUM.

A 150-kw. Detroit furnace, with a thinner lining than the regular 150-kw. brass furnace, so as to give a capacity of 1,000 to 1,200 pounds of aluminum has been installed for aluminum melting by the Storm Peak Potash Co., Denver, Colo., but no data are yet available on its performance.

UNIVERSAL ENGINEERING CORP. ROCKING FURNACE.

The Universal Engineering Corp., Baltimore, Md., applied early in 1919 for a license to manufacture rocking furnaces for sale under the Bureau of Mines patents and built a furnace at the plant of Jos. Brenner & Co., Hagerstown, Md., the drawings for which show that the design embodies many of the improvements worked out by the Detroit Electric Furnace Co. over the bureau's experimental furnace, apparently differing only in minor details of design from the Detroit furnace.

The furnace was operated in August, 1919, and was reported by the electrical engineer of the Universal Engineering Corp. as working very well, but as having some minor faults in mechanical construction. Late in October the electrical engineer reported it had been decided practically to rebuild the furnace and to correct all the faults of construction that had yet been discovered before submitting the furnace for the inspection and test by the Bureau of Mines that must be made before a license to sell the rocking furnace can be issued. No quantitative data on the performance of the furnace has been submitted to the bureau, but it was stated that in the first trials yellow brass scrap was melted, and then skimmings were tried, the recovery of metal being so high that the furnace was kept at this work for some time, though some trouble was met by the slag building up onto the lining. The furnace was then used for recovery of lead residues. The furnace is said to have operated for a period of 8 months on a corundite lining in such service. How nearly continuous the operation was during that period is not known. Repeated requests to the Universal Engineering Corp. for data on the performance of the furnace failed to secure any data whatever, and since the work with the furnace appeared to have ceased, notification was sent to that firm by the Director of the Bureau of Mines in July, 1920, that in view of the firm's failure to supply data and to continue development of the furnace, cooperation of the bureau was at an end and a license would not be issued.

REVOLVING BRASS FURNACE.

In 1917 one revolving oil-fired open-flame brass furnace was put on the market ⁴⁴ and another ⁴⁵ was advertised late in 1919.

⁴⁴Anonymous, A noncrucible revolving furnace, *Metal Ind.*, vol. 16, 1918, p. 38.

⁴⁵Anonymous, A continuous revolving noncrucible metal melting furnace, *Metal Ind.*, vol. 17, p. 498, 1919.

Following publication of the experiments of the Bureau of Mines with the rocking type of furnace, and the successful commercial use of the Detroit furnace, the idea of moving an electric brass furnace while running was taken up by various designers and builders of electric brass furnaces and applied to various furnaces, on the operation of which very little information is yet available.

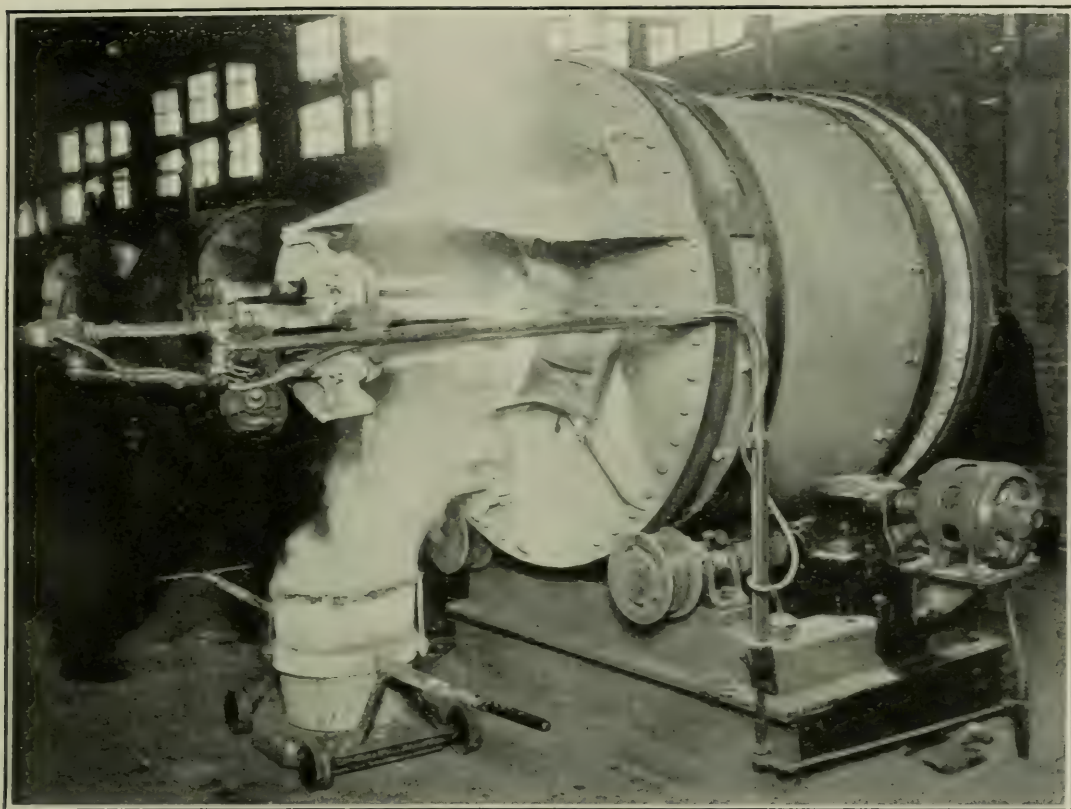
The gyrating or revolving Thomson zigzag-resistor furnace design and the Harvey revolving-furnace design have already been described. Another furnace, the Booth, has been designed, in which the furnace is revolved in one direction instead of rocked back and forth. The Bureau of Mines considered the complete revolution of the furnace instead of rocking it, and the use of a taphole, as well as the use of more than one set of electrodes for polyphase current, as will be seen from the patents,⁴⁶ but did not construct a rotating or revolving form of furnace for the following reasons: First, continuous rotation of the furnace involves the use of some sort of a sliding contact in the electrical circuit which is not extraordinarily difficult to handle on a small furnace taking, say, only 100 kv. a. though even in the smaller furnaces trouble would be expected in the maintenance of such contacts amid the dust and dirt of a foundry. But in a furnace of sufficient capacity to make it generally useful, as a 1-ton, 300-kv. a. furnace, the use of a moving contact to carry a current of around 2,500 amperes hardly appears to be desirable.

There must also be a revolving joint in the water line to the electro coolers, which must be carefully maintained to keep it from leaking. The pains taken by Stassano⁴⁷ to construct his later forms of the moving Stassano furnace to allow the use of cables and water connections having a permanent and solid connection in place of the brushes, slip-rings, etc., used in the early rotating form, shows the conclusions reached on this point in attempts to employ a sliding contact on a large electric furnace under foundry conditions.

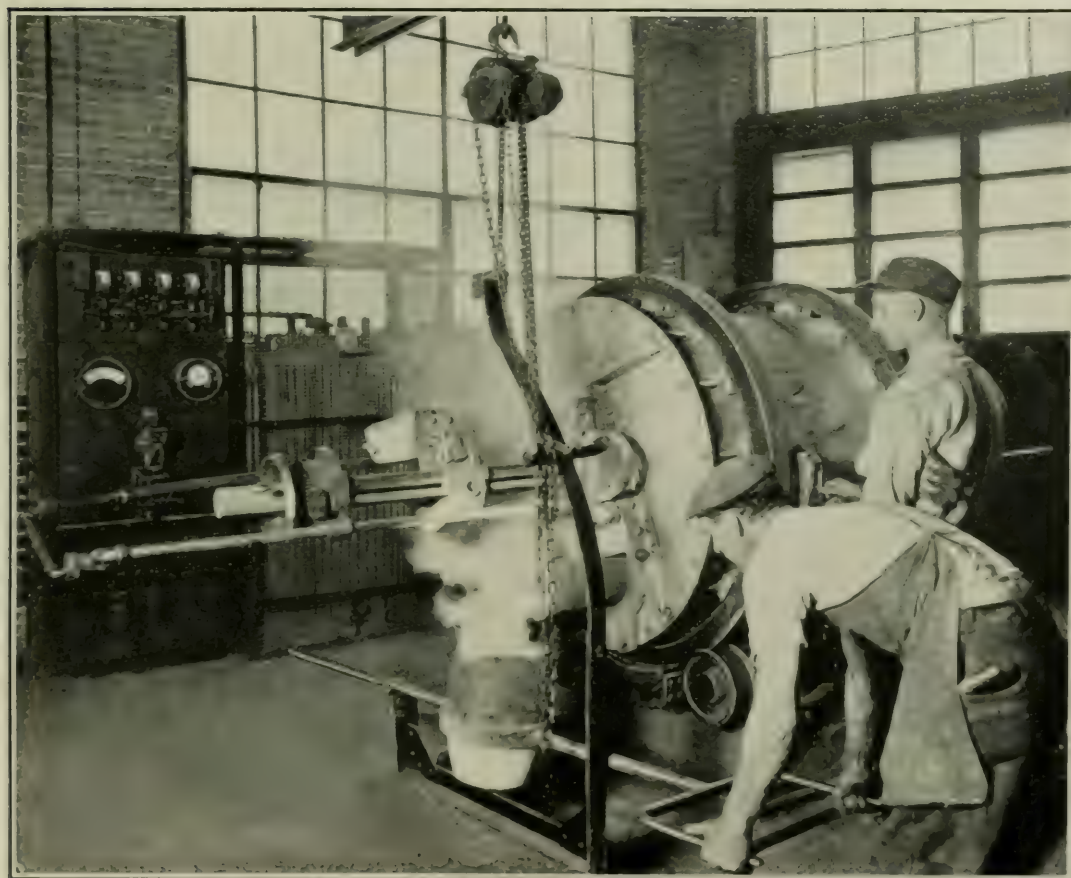
Second, a furnace which admits only of continuous rotation in one direction can not be started in motion when it contains a partly solid charge containing heavy ingots or chunks of metal, as these may be carried up by the motion of the furnace so far that they do not fall until they are over the electrodes, and when they do fall, they hit the electrodes and break them. On a charge of all borings, the furnace could be rotated with comparative impunity, as the borings might be too light to break the electrodes, but on an ingot charge, it is necessary either to use a charge far under the proper capacity of the furnace or to wait till the material is almost all melted before starting to

⁴⁶ Gilbert, H. W., and Lehr, J. M., U. S. Patent 1,201,224, Oct. 10, 1916.

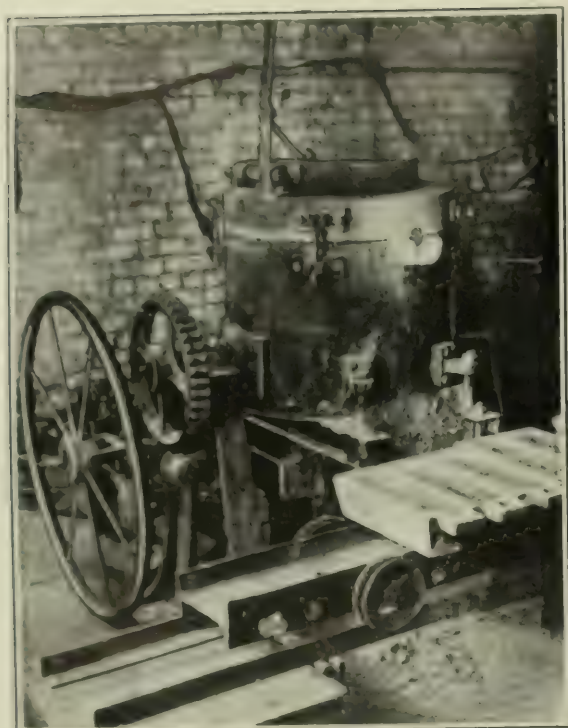
⁴⁷ Schmelz, E. M. A new electric steel casting plant: Met. and Chem. Eng., vol. 11, 1913, p. 799; Stassano, E. I., U. S. Patent 1,024,657, Apr. 30, 1912; 1,059,499, Apr. 22, 1913; 1,105,859, Aug. 4, 1914.



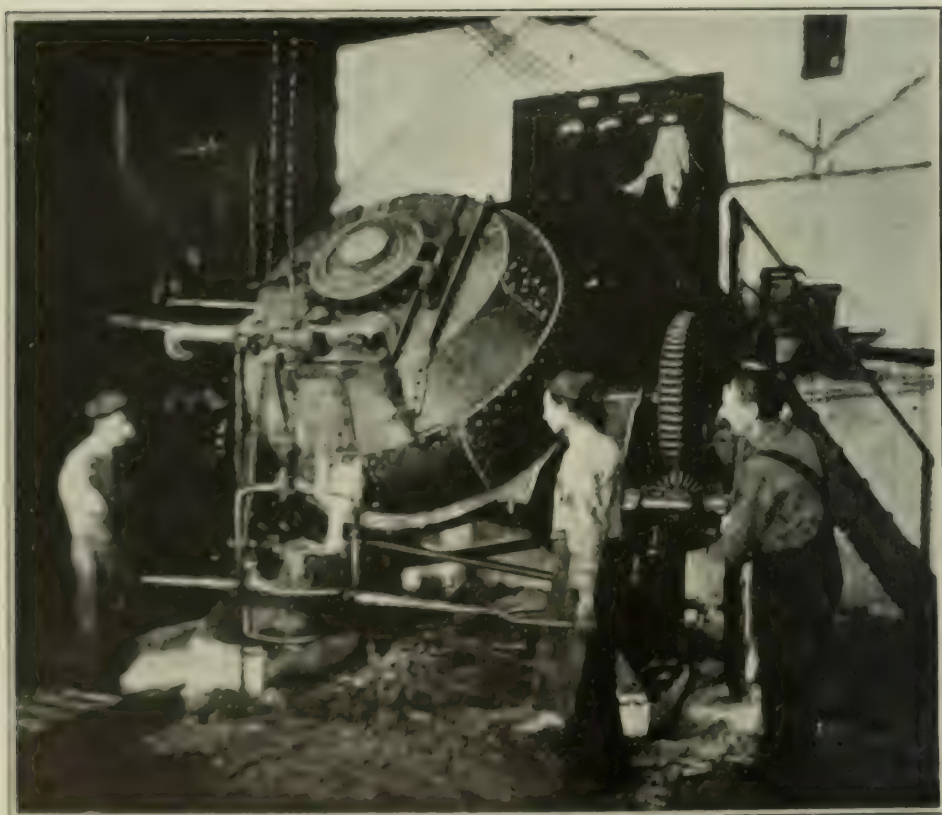
A. A ONE-TON BOOTH ROTATING FURNACE, SHOWING AUTOMATIC ELECTRIC CONTROL



B. A 500-POUND BOOTH ROTATING FURNACE.



1. FIRST COMMERCIAL AJAX-WYATT FURNACE.



2. HEATING GRASS FURNACE TESTED AT THE PLANT OF THE
AJAX METAL CO.

rotate. Inspection of figure 32 will show how rotation of the furnace past a certain point in the first three or four views would cause the ingots to tumble over on the electrodes.

On alloys high in zinc it is essential that the furnace start to move as soon as an appreciable quantity of molten metal has accumulated so that any of it which has become pocketed under the arc may be poured out of the pocket. If it is retained, it becomes superheated, just as in any stationary indirect-arc furnace, and the pressure of zinc vapor becomes so great that the furnace can not be kept tight, and loss of zinc ensues. Just as it was found that the 600-pound Snyder furnace could be kept tight on an alloy high in lead, though the 1-ton furnace could not, so the difficulty of keeping an indirect-arc furnace tight on alloys high in zinc increases as the size increases. A 1-ton furnace melting 60:40 brass can be operated only with great difficulty, if at all, unless the stirring of the metal by rocking is begun long before enough of the charge has melted to allow wide rocking of the furnace without breaking the electrodes. Hence the rocking furnace has been provided with means for varying the rocking angle from the "safe rock" to the "full rock" as the melting progresses.

These reasons, and various other minor ones having to do with convenience in operation, were sufficient to outweigh the two advantages of complete rotation: (1) The washing of all the furnace wall with metal instead of about 90 per cent of it; (2) the greater stability of a solid lining instead of one pierced by the opening for the charging door.

BOOTH REVOLVING FURNACE.

The Booth ⁴⁸ furnace is a rotating indirect-arc furnace, which in a 250-pound size was first tried out at the plant of Leitel Bros., Chicago, the first heat being made on May 17, 1919. A 500-pound size of this furnace is shown in Plate XX, *B*, and a 1-ton size in Plate XX, *A*; it is a horizontal cylinder mounted on rollers and with the electrodes entering on the horizontal axis, adjustable by electrode holders, the design closely resembling that of the rocking furnace save that the metal is tapped from one end and charged from the other by opening a door which carries one electrode and its holder. This method of tapping and charging has been criticised as inconvenient by some users. Current is carried to the electrodes by flexible leads connected to two bronze shoes on the shell and insulated from it which take current from the main cables by sliding contacts.

⁴⁸ Booth, C. H., The Booth electric rotating brass furnace, *Iron Age*, vol. 103, 1919, p. 1699; *Metal Ind.*, vol. 17, 1919, p. 317, vol. 18, 1920, p. 456; *Chem. Met. Eng.*, vol. 21, 1919, p. 637; *Foundry*, vol. 18, 1920, p. 994; Booth, W. K., U. S. Patent 1,332,795, Mar. 2, 1920, and 1,380,767, June 7, 1921; Harper, C. W., U. S. Patent 1,336,073, Jan. 18, 1921.

The makers of the furnace say that when turnings or similar materials are melted, rotation can be started at once; but when ingots are melted rotation must be delayed till the metal is partly melted in order to avoid electrode breakage. Emphasis is laid on the fact that a small furnace of this type could be lifted off bodily and carried to the molds for pouring by a crane; it is not known whether this has been actually tried.

The output of a 250-pound furnace is given as 1 ton in $7\frac{1}{2}$ to 8 hours, and the power consumption is stated to be as low as 240 kw. h. per ton with the furnace hot; 300 kw. h. per ton is claimed on 8-hour operation, and a lining life of 600 to 1,000 heats is claimed.

Metal losses are low; dirty concentrates from floor sweepings that give 30 to 40 per cent loss in crucibles showed $17\frac{1}{2}$ per cent gross loss. Yellow brass turnings have been melted with a gross loss of $1\frac{1}{2}$ per cent; yellow ingot with 1 per cent, and red brass and bronze, below 1 per cent.

On individual heats of clean, yellow, and red brass, in which great care was taken not to overheat the metal, figures of 0.4 per cent and 0.22 per cent, respectively, were obtained. A test on the 250-pound furnace on red brass showed a production of 2,000 pounds in 9 hours, at 400 kw. h. per ton with an electrode consumption of 3 pounds per ton and a metal loss of 0.75 per cent. Further data on the operation of the 250-pound Booth furnace at Leitel Bros. has been given.⁴⁹ In the month of June, 1919, the furnace run on one-shift, 9-hour operation, melted 35,215 pounds, averaged 480 kw. h. per ton, and used 4 pounds graphite electrodes per ton. The power factor of the furnace installation itself, on the secondary side of the transformer, was 70 to 71 per cent; that on the primary side, including the transformer, was 63 per cent. This power factor is so low that it involves a power factor penalty in most power contracts. It was made so low in order to make the arc maintain itself with the least attention, so that the operator would not be forced to stay at the furnace all the time for adjustment of the arc. As the output of a 250-pound furnace is so low, the labor cost with one man per furnace would become excessive. Another way out of the dilemma would be to attach a device for automatic electrode control.

During two weeks' operation in June the following metal-loss data were obtained:

	Charged.	Obtained.	Loss.	
	Pounds.	Pounds.	Pounds.	Per cent.
Red brass.....	14,787	14,667	120	0.81
Yellow brass.....	1,961	1,933	28	1.40
Yellow brass turnings.....	408	350	58	14.21

⁴⁹ Electric Brass Furnace reduces foundry costs, Elec. World, vol. 74, 1919, p. 1107. Foundry test of rotating furnace, Chem. and Met. Eng., vol. 22, 1920, p. 136.

The borings were said to contain 8.28 per cent oil and 5.38 per cent nonmetallic, or 13.66 per cent, leaving a net metal loss of 0.55 per cent.

The power consumption on this two weeks' run was 441 kw. h. per ton. Booth⁵⁰ states that the 250-pound rotating furnace linings have lasted 550 to 600 heats and claims for the 500-pound size, in 9-hour operation, an output of 3,800 pounds of red brass at 310 kw. h. per ton. In a run of one month, during which 40 tons were melted, the power consumption was 370 kw. h. per ton, and the electrode consumption was 3.7 pounds per ton.

The first lining of the 250-pound furnace is said to have lasted almost 500 heats. The makers recommend that the power factor be made 70 per cent in order to cut down the amount of hand regulation required. In this case it is stated two men can charge and handle three 250-pound furnaces.

At the Fulton Harwood Brass Works, South Bend, Ind., in the period June 6 to July, 1920, 40 tons of red brass were melted at 371 kw. h. per ton in the 500-pound Booth furnace; 3.7 pounds electrodes were used per ton. The metal loss was estimated at 0.75 per cent.

In other plants operating the 500-pound furnace on yellow brass, 10-hour operation, the power consumption is stated to run close to 300 kw. h. per ton and the output around 2½ tons.

The usual lining life is given as 600 heats.

Booth⁵¹ has recently given details of the operation of 250 and 500 pound furnaces, but no data have been published on the operation of the 1-ton furnace.

Bragg⁵² stated that as far as he was able to see the 1-ton Booth furnace at the Michigan Smelting and Refining Co. "looked satisfactory, but he was not ready to speak with certainty at that time."

A Booth furnace is installed at the Bridgeport Brass Co., but this firm states:⁵³ "The Booth furnace was not a success, as the type of lining furnished did not stand up at all well."

The furnace is made for 110-volt single-phase current. The furnace is said to have been designed in capacities of 150, 250, 500, 1,000, 2,000, and 3,000 pounds. The transformer capacity for all sizes is not given, but that used for the 250-pound furnace is 75 kv. a.; for the 500-pound, 125; for the 1,000, 180; and for the 2,000, 300. The price of the 250-pound furnace, without transformer, primary switch, etc., was said to be about \$3,000 in September, 1919. The additional equipment necessary for a complete installation would cost several hundred dollars more.

⁵⁰ Booth, C. H., Later type furnace, Foundry, vol. 48, 1920, p. 466.

⁵¹ Booth, C. H., Booth rotating electric furnace, Metal Ind., vol. 18, 1920, p. 456.

⁵² Bragg, C. T., Discussion, Metal Ind., vol. 18, 1920, p. 447.

⁵³ Webster, W. R., personal communication, Aug. 24, 1921.

The furnace seems to be applicable in small sizes, but its degree of availability in large sizes has not yet been thoroughly shown.

AMERICAN REVOLVING FURNACE.

A later entrant into the field was the American indirect-arc furnace, designed by the American Metallurgical Corp. This furnace was first advertised^{53a} late in 1919. A description given by Ryan⁵⁴ shows that the furnace, though claimed to be an adaptation of the Weeks zinc furnace, deviates greatly from the original design of Weeks, following very closely indeed except in one particular the design of the Detroit rocking furnace.

Instead of the stationary electrodes of the Weeks furnace, the electrodes and supports are attached to the furnace shell and move with it. In the Weeks patent⁵⁵ a handwheel is shown, and the photograph illustrating Hansen's⁵⁶ paper on the Weeks furnace shows a motor, evidently reversed by hand, if at all, by which the Weeks furnace could be turned over now and then to interchange roof and hearth in order to obtain uniform wear of the lining as contemplated by Weeks for work on zinc. Ryan, however, provides a system "of automatic switches by which the drum can be rotated to any percentage of its circumference at the will of the operator, a special control, making it possible to set operation at any given point"; it is analogous to the control device previously used in the Detroit rocking furnace for automatic control of rocking and for varying from "safe rock" at the start to "full rock" at the end.

The furnace is also designed to be rotated completely if desired, although the charging door and pouring spout are on the circumference, and while a pouring spout can be plugged so as to be fairly safe against pressure of molten metal, it is difficult to see how a large charging door can be made safe against such pressure. One would also expect that metal would run around the door joint, solidify, and prevent the opening of the door.

The American furnace was designed for brass melting and aimed to prevent metal loss through stirring by rocking; the Weeks furnace was designed for zinc, never tried on brass, and when tried on copper was kept stationary during melting.

The American furnace design has the charging door and pouring spout on the circumference of the shell, like the Detroit rocking furnace, instead of on the ends, as in the Booth. It follows Booth in

^{53a} *Brass World*, vol. 15, 1919, October. Front cover.

⁵⁴ Ryan, F. L. Week's electric rotating furnace as applied to the brass industry, *Metal Ind.*, vol. 17, 1919, p. 519. See also Adheson Graphite Co. Brass Melting (pamphlet) August, 1920, p. 29.

⁵⁵ Weeks, C. E. U. S. Patent 949,511, Feb. 15, 1910.

⁵⁶ Hansen, F. A. Electric melting of copper and brass: *Trans. Am. Inst. Metals*, vol. 6, 1912, p. 116.

carrying the current by a sliding brush contact from motor brushes attached to the leads to a copper collector ring, carried on each end of the furnace instead of on rings attached to the circumference of the shell as in the Booth, thus avoiding the swinging cables of the Detroit furnace, but involving the use and maintenance of a sliding contact for a heavy current, and of a moving joint in the water connections. As in the Detroit and Booth furnaces, graphite electrodes were to be used.

An American furnace was ordered by the York Hardware and Brass Co., York, Pa., but was never delivered, and the Weeks patent, on which the design of the American furnace was stated to be based, which had been acquired by the American Metallurgical Corp., was next acquired by the Electric Furnace Construction Co., of Philadelphia, which stated in June, 1921, that it planned to put an electric brass furnace on the market.

The American furnace appears not to have been constructed or tested, and it is not known whether the Electric Furnace Construction Co.'s projected furnace is to follow the design of the American furnace or not.

MOORE FURNACE.

The "Moore Rapid 'Lectromelt Furnace" has been advertised by the Pittsburgh Electric Furnace Corp., but no detailed description of the exact construction has yet been given out, and no commercial installations have been made, though one experimental furnace is said to have been constructed. From the patent^{56a} it appears that the furnace is of the indirect arc type, the electrodes being mounted in a stationary roof, the body of the furnace being a cylinder set on end with its axis off the vertical. The body is revolved or oscillated about its axis. The revolving of the tilted furnace is to stir the charge. Like the Volta furnace, this does not wash the roof or much of the side walls with molten metal.

The advertisements⁵⁷ state, "Heat is transmitted to the charge by distributed radiation and reflection only. Arcs are struck between the electrodes rather than against the charge. Segregation and volatilization are minimized by tumbling the charge. They use polyphase or single-phase power."

The furnace is designed in 250, 500, 1,000, and 2,000 pound sizes. It is claimed to be especially adapted for melting brasses high in zinc.

^{56a} Moore, W. E., U. S. Patent 1,378,972, May 24, 1921.

⁵⁷ Metal Ind., vol. 18, February, 1920, advt. p. 10; June, 1920, p. 91; Elec. World, vol. 75, Apr. 24, 1920, p. 98.

REARDON FURNACE.

Still another rocking indirect-arc design has been described by Reardon¹⁸ in which the oil burners of a Schwartz open-flame oil furnace are to be replaced by electrodes between which an arc is drawn, and the furnace is to be rocked mechanically on its trunnions. Reardon says that the design for the adaptation of the Schwartz furnace to electric heating was begun in December, 1913, but no figures on the performance of an actual furnace were available in August, 1921. On account of the location of electrodes, charging door, and pouring spout, only about half the lining can be washed by the metal.

The furnace is designed to take 300 kw. on a 1-ton size, at 220 volts. With as long an arc as 220 volts will give, and with the electrodes placed close together in the location of the burners, the treatment of the unwashed roof above the arc would be severe, and refractory troubles might be expected.

As the cost of the furnace shell is but a minor part of the total cost of an electric, it would appear wiser to the writers to use an electric furnace designed as such than to attempt to make over an oil furnace of this form into an electric furnace.

VOLTA FURNACE.

Although the original gyrating Stassano furnace was not applied to nonferrous melting,¹⁹ the design has recently been resurrected, the furnace being provided with a mechanically simpler gyrating device, so made as to give the furnace a greater tilt and hence greater stirring than the original Stassano. The furnace is a three-phase, indirect-arc furnace with the electrodes 120° apart and slightly tilted downward from the horizontal. Provision is made for changing the angle of the electrodes, much as is done on the side electrodes of some Rennerfelt furnaces.

The stirring action is obtained by mounting (see fig. 32) between the base and the bottom of the furnace shell, a rotatable ring actuated by motor-driven gearing and resting on rollers. Several peaks of different heights are carried by this ring, each peak carrying a roller which runs underneath a track on the bottom of the furnace shell.

The shell has a projection carrying a roller, which runs up and down in a vertical, fixed track, thus preventing sidewise motion of the shell. As the ring revolves it alternately raises and lowers each point on the bottom of the furnace shell, giving a gyrating motion

¹⁸ Reardon, W. J. Electric melting in an oil furnace, *Metal. Ind.* vol. 18, 1920, p. 207.

¹⁹ Anonymous. Three-phase electric brass furnace of novel design; *Canadian Chem. Jour.*, vol. 4, 1929, p. 115.

to the whole furnace. Pouring is done also by use of the motor-driven ring.

The motion of the furnace is stopped when the spout is in its highest position, the tap hole is opened and cleaned, being then above the metal level, the ring is started in motion and the spout lowered, thus pouring the charge.

The roof is made in the form of a parabola, so as to reflect the heat from the arc directly down on the bath. It is claimed that since the three-phase arc covers a wider area than a single-phase arc of equal kilowatt, and the source of heat is therefore not so localized, that the gyrating motion gives sufficient stirring to avoid local overheating of the surface of the melt.

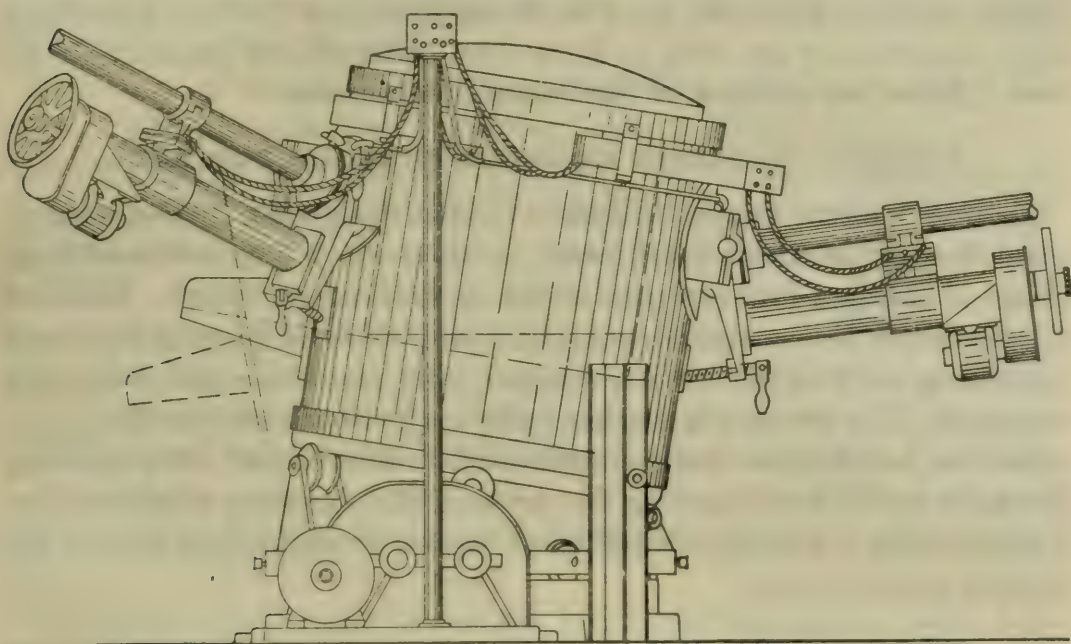


FIGURE 32.—Gyrating Stassano-type furnace sold by Volta Manufacturing Co.

The charge is always below the electrodes so that the electrodes can not be broken by the charge falling on them. There is of course no gain in thermal efficiency due to cooling the roof to the temperature of the bath, such as is obtained in the rocking and rotating furnaces.

The furnace of a 1-ton size was briefly tested at the plant of the Titanium Bronze Co., Niagara Falls, N. Y., and it is claimed that "as low as" 225 kw. h. per ton of yellow brass and 300 kw. h. for aluminum bronze was obtained. These figures do not include any preheating and are calculated for continuous 24-hour operation. The metal loss is said to have been under 1 per cent; but it is not stated whether this was on yellow brass or aluminum bronze.

Data are lacking by which to fix definitely the efficiency of the metal losses on this furnace. If the stirring is adequate to avoid surface overheating, it would be expected to show metal losses of the

same order as those of the other moving indirect-arc furnaces. Its power consumption per ton would be higher than that of the furnaces in which the lining is thoroughly washed by the metal.

It would be useful in localities where a single-phase arc load is not acceptable to the central station company, but where a three-phase arc load can be handled.

The furnace is designed in 500 pounds, 125 kw.; 1,000 pounds, 175 kw., and 1-ton, 300 kw. sizes, and is sold by the Volta Manufacturing Co., Ltd., Welland, Ontario, Canada. The electrodes can be adjusted by hand or from the switchboard when motor control is used, or the furnace could be provided with automatic electrode control.

A demonstration furnace is installed at the Fitzgerald Laboratories, Niagara Falls, N. Y. One furnace each of the 500, 1,000, and 2,000 pound sizes are said to have been ordered, but delivery of all was deferred on account of the business depression.

ROCKING METALLIC RESISTOR FURNACE FOR ZINC.

Collins²⁸² of the General Electric Co. has designed a three-compartment furnace in which solid metal, as zinc, which is to be freed from dross, is charged into one part of the central compartment. Holes at the bottom of this compartment admit molten metal from the two end chambers, each of which is provided with metallic resistor heating elements. The furnace is mechanically rocked back and forth so as to wash the solid metal with superheated molten metal, thus melting the solid metal, but trapping the dross in the charging compartment. Clean molten metal may be ladled or tapped from another part of the central compartment.

SUMMARY ON MOVING INDIRECT-ARC FURNACES.

It is interesting to note that in addition to the makers of the furnaces built under the Bureau of Mines patents, seven other brass furnace designers—Thomson in his gyrating resistor furnace, Moore in the Pittsburgh Electric Furnace Co.'s rotating furnace, Booth in a rotating indirect-arc furnace, Ryan in the American rocking indirect-arc furnace, Reardon in his adaptation of the Schwartz oil furnace into a rocking indirect-arc furnace, and the makers of the Volta furnace, as well as Hervey in his furnace design—have taken up the principle of preventing local overheating of the surface of the metal through stirring by means of motion of the furnace while running a principle first applied to a commercial electric furnace by Stassano and worked out for electric brass melting by the Bureau of Mines. Collins also makes use of a rocking device in his zinc furnace. The value of the principle appears to be fully established. It

²⁸² Collins, E. F., U. S. Patent 1,578,526, May 17, 1921.

takes the indirect-arc type of furnace beyond the field to which the stationary indirect-arc furnaces are limited, that of alloys low in zinc, and thus produces a furnace suited metallurgically for use by plants that have to melt a large variety of alloys in the same furnace, showing not only a low power consumption per ton but low metal losses on a wide range of alloys.

Due to absorption by the moving charge before pouring of heat stored in the furnace walls, the temperature of the furnace walls and hence the radiation losses are reduced, and on account of the smaller heat storage in such a furnace than in furnaces of the reflected heat type, the moving indirect-arc type can be used on single-shift operation, without night heating, showing on such operation materially higher production and lower power consumption than do the types having a high heat storage.

The moving indirect-arc type is therefore suited especially for use by jobbing foundries, smelting and refining plants, and by plants operating only one shift per day. It is somewhat less simple to operate than stationary direct or indirect arc furnaces, than the reflected heat types, or than the vertical ring induction furnace. In flexibility, ability to operate on any alloy or any number of shifts per day, it surpasses all these other types. It holds its own on metal losses with any of the others in the field they can cover; in ability to operate at a low power consumption per ton, even in small sizes, it is surpassed only by the vertical ring induction type and possibly by the high-frequency current type. Its lining life and its electrical characteristics though not as satisfactory as those of some of the other furnaces are yet very good.

The main advances to be looked for in moving indirect-arc furnaces are in the addition of devices for rapid mechanical charging, to which those having the charging door on the circumference of the shell are well adapted, and for automatic control of the arc. Advances in the knowledge and use of better refractories for electric furnace use will improve the reliability of this as of all other types.

The principle of a moving indirect-arc electric furnace for brass has been accepted rapidly and widely, as may be seen by the following summary: The first test of such a furnace on brass was in August, 1915; the first semicommercial test in May, 1917; and the first commercial furnace started operation in August, 1918. On August 1, 1921, 100 rocking or rotating furnaces taking over 21,000 kw. were in operation at or being installed in nonferrous alloy plants in the United States; and half a dozen furnace makers or designers have incorporated the principle of moving an electric brass furnace while operating it into designs brought out since the experiments with the rocking furnace were published.

FURNACES IN WHICH THE METAL ITSELF IS THE RESISTOR.

In order to attain the highest thermal efficiency in an electric furnace the heat should be generated within the charge itself, not at a distance from the charge. As small a part as possible of the heat should be forced to the walls or roof before it is reflected back to the charge, nor should it be forced to pass through anything, like a crucible, which would baffle the flow of heat.

This principle of generation of heat within and in contact with the charge is the basic principle of efficient heating. It is seldom practical in fuel-fired furnaces, though it obtains in cupolas and blast furnaces, the most efficient of the type. It is more often possible to construct an electric furnace on this principle, which is carried out in all the most successful electric furnaces. Such electric furnaces as deviate from it do so only because electrical, metallurgical, or structural reasons make it impractical.

Electric furnaces for making graphite, carborundum, and carbon bisulphide generate the heat in or within the charge itself. Calcium carbide furnaces and ferro-alloy smelting furnaces usually operate either with the arc buried in the charge or with the charge as resistor.

Steel-melting furnaces which use carbon electrodes can not be so operated, but the direct-arc types of furnace, in which at least 95 per cent of the world's output of electric steel is melted, do the next best thing by generating the heat directly in contact with, though above, the charge.

Gin⁶¹ tried to make a furnace in which a long, narrow channel between two electrodes was filled with the material to be melted, and heat was to be generated by the resistance of the charge itself. The furnace could not be operated even on steel, and as the resistance of nonferrous alloys is so much lower than that of steel, it would be even⁶² more impractical on brass than on steel. If an induction furnace is constructed by doing away with the electrodes and by making the charge the secondary of a transformer, steel can be melted by the generation of heat in the charge itself.

Inasmuch as the induction furnace allows the generation of heat in the steel itself, it might seem that induction furnaces would be the most logical type for use on steel. However, there is another factor entering in to affect its usefulness—the usual basic principle of an induction furnace shown in figure 33 and exemplified in the Colby-Kjellin,⁶² Frick, Roechling-Rodenhauser,⁶³ and other induction fur-

⁶¹ See Stansfield, A., *The electric furnace* 1914, p. 247.

⁶² For brief description of the principles on which an induction furnace operates, see Clamer, G. H., *Melting brass in the induction furnace*, Jour. Am. Inst. Metals, vol. 11, 1917, p. 382.

⁶³ Kjellin, F. A., U. S. Patent 682,088, Sept. 3, 1901.

⁶⁴ See Rodenhauser, W., and Schoenawa, J., *Trans. by vom Baur, Electric furnaces in the iron and steel industry*, 1917, p. 172.

naces demands that the steel be contained in one or more horizontal ring-shaped troughs, which form the secondary circuit. The ordinary induction furnace thus has a huge volume and huge wall space for a comparatively small metal capacity, and the electrical requirements make the type violate the second principle of thermal efficiency, that the furnace shall be as small as possible for a given capacity in order to avoid thermal leakage through excessive wall area. For this reason the thermal efficiency is not as good in a steel furnace of the horizontal ring induction type as in a direct-arc furnace. Its main theoretical advantage having been thus overbalanced, only its avoidance of the use of electrodes remains to compare with the disadvantages of inconvenience, low-power factor, and lower slag temperatures, which tend toward slower refining.

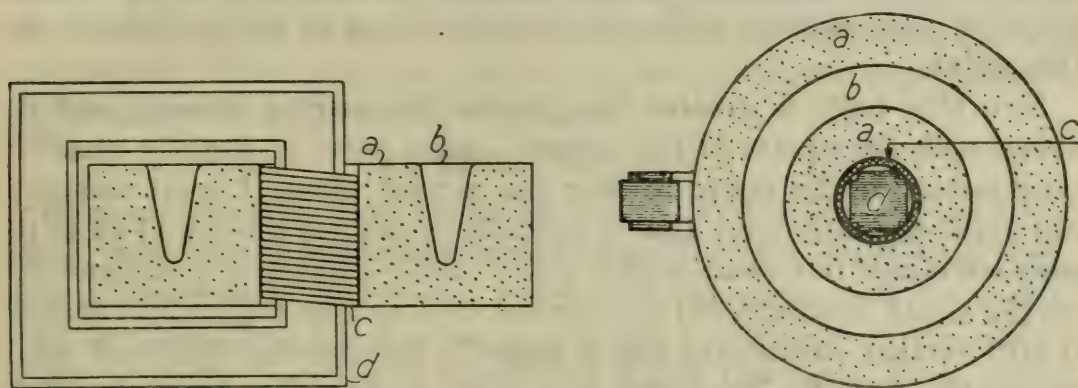


FIGURE 33.—Diagram of horizontal ring induction furnace: *a*, stamped lining; *b*, crucible; *c*, primary coil; *d*, core.

The induction furnace for steel melting in all countries with the possible exception of Germany has fallen back steadily till it almost can be classed as an obsolete type. The General Electric Co., however, has again attacked the problem of the induction furnace for steel and recently brought out a new modification, which is described by Unger and Scharschu.⁶⁴

HORIZONTAL RING INDUCTION FURNACES FOR BRASS.

Besides the disadvantages which have made the ordinary induction furnace of little value for steel, there is another which makes it inapplicable to copper, brass, or bronze. This is the "pinch effect," which has been described by Bary⁶⁵ and by Hering.⁶⁶

Briefly stated, the "pinch" phenomenon is due to the fact that currents flowing in the same direction through parallel conductors attract each other. This is the converse of the principle of the von

⁶⁴ Unger, M., and Scharschu, C. A., New type of induction electric furnace: *Iron Age*, vol. 108, 1921, p. 344.

⁶⁵ Bary, P., La pulverisation électrique des métaux: *L'industrie électrique* No. 224, Apr. 25, 1901, p. 178.

⁶⁶ Hering, C., A practical limitation of resistance furnaces, the "pinch" phenomenon: *Trans. Am. Electrochem. Soc.*, vol. 11, 1907, p. 329; The working limit in electrical furnaces due to the "pinch" phenomenon: *Trans. Am. Electrochem. Soc.*, vol. 15, 1909, p. 255.

Schlegell "repelling arc," where the fact that currents flowing in opposite directions through parallel conductors repel each other is made use of to force the electrodes (which are pivoted so as to be free to separate) apart and start the arc. The current flowing in a single conductor also tends to attract the parts of a cross section of that conductor one to another. That is, a conductor through which a current is flowing tends to shrink and become more dense. Solid conductors can not yield to this force, but a liquid one, like mercury or molten brass, can do so.

If the conductor has exactly the same cross section throughout, the contracting forces are balanced and nothing happens, but if the cross section is smaller at one point, as can not fail to be the case in the secondary of an induction furnace through the dropping in, for example, of a piece of brick from the roof, the forces no longer balance at this point.

Now this force is greater the greater the current density, and it varies with the square of the current. At a point of slightly smaller cross section in the liquid resistor the current, then, if great enough, can exert so much force that it actually constricts the liquid as if it were contained in a sausage skin and a rubber band were put about it. As the liquid is constricted the current density gets higher and makes it still further constricted till it actually pinches the liquid off and breaks the circuit. The metal will then run together again, but the pinch force again makes it separate. At high current densities, as a result, the metal can not be kept together long enough for sufficient power to be supplied to keep it molten.

Materials of comparatively high electrical resistance at temperatures above their melting points, such as steel, platinum, and nickel and its alloys, can be melted in the induction furnace, because the voltage it takes to overcome their resistance is high enough that sufficient power kilowatts can be put into them to melt them and not exceed the current that can be used without making the pinch force exceed that of gravity.

But with materials of relatively low electrical resistivity at their melting point, such as copper, aluminum, brass, and bronze, the voltage required to overcome their resistance is very low, hence huge currents are required to generate enough heat to melt them, since $\text{power (watts)} = \text{volts} \times \text{amperes} \times \text{power factor}$. As the power factor in ordinary induction furnaces is low the current (amperes) must be high when the voltage or the electrical resistance is low. As the pinch force varies with the square of the current it turns out that copper, aluminum, brass, and bronze are all affected by the pinch force in a horizontal ring induction furnace, and that consequently it is impossible, or at least impracticable, to melt them in such a furnace.

This conclusion does not rest on theory alone. Fitzgerald⁶⁷ cites a case where aluminum could be just melted but not superheated at all because of the rupturing of the ring by the pinch force. By working with an extremely shallow ring of steel so that the force of gravity was not enough to overcome the pinch force, the phenomenon was duplicated with steel.

SPENCER FURNACE.

The same phenomenon was noted in an attempt to melt brass in a small laboratory induction furnace at the Massachusetts Institute of Technology, and in a test made at the Pierce Arrow Motor Car Co. several years ago in a furnace built by Mr. E. B. Spencer it was found that on nonferrous alloys of high conductivity the pinch effect was so great as to make the regular type of induction furnace impractical. The American Brass Co. had a similar experience in a trial of an induction furnace on brass.

HARDEN FURNACE.

Harden⁶⁸ suggests that for melting brass and aluminum the horizontal ring induction furnace should be built with a conducting ring-shaped crucible, as of fire-clay graphite mixture, to hold the metal, with the idea that by generating a large proportion of the power in the crucible the current density at which the pinch force starts to give trouble may not be exceeded.

GEHRKENS FURNACE.

Gehrrens⁶⁹ also suggests avoiding pinch-effect troubles on a horizontal ring induction furnace for brass or aluminum by having a conducting secondary other than the charge itself as a permanent part of the furnace.

SOLOMON FURNACE.

Solomon⁷⁰ patents a horizontal ring induction furnace in which the metal is contained in an annular crucible that can be removed to pour. The crucible would be excessively fragile, and the furnace was not designed especially for brass melting.

GREENE FURNACE.

Greene⁷¹ patents a horizontal ring induction furnace designed for melting copper, brass, bronze, and aluminum, in which the primary circuit is brought into the refractory lining close to the secondary, which is made up of the material to be heated. The primary is made a resistor, and the heat generated in it is transmitted through

⁶⁷ Fitzgerald, F. A. J., Discussion, Trans. Am. Electrochem. Soc., vol. 15, 1909, p. 278.

⁶⁸ Harden, J., U. S. Patent 977,303, Nov. 29, 1910.

⁶⁹ Gehrrens, E. F., assignor to General Electric Co., U. S. Patent 1,011,769, Dec. 12, 1911.

⁷⁰ Solomon, H. G., U. S. Patent 1,081,164, Dec. 9, 1913.

⁷¹ Greene, A. E., U. S. Patent 1,078,619, Nov. 18, 1913.

the refractory lining to the hearth or secondary. Both primary and secondary thus are to be sources of heat. This principle practically amounts to an attempt to run a brass furnace with a metallic resistor, the primary, as one of the main sources of heat. No metallic resistor of suitable physical properties is available at a price that would allow it to be used in a commercial brass furnace. The furnace does not appear to have been constructed or tested.

KJELLIN FURNACE.

Rowlands⁷² cites a test on brass of a Kjellin furnace provided with a conducting crucible in which the pinch effect was overcome. He states also that in a three-phase furnace without a conducting crucible the pinch effect was less intense than in a single-phase. Brass is said to have been melted in the three-phase furnace at 165 kw. h. per net ton, a very low figure.

Arnold⁷³ stated in 1910 that tests were to be made at Sheffield University on a comparison of melting brass, bronze, and German silver by coke, and in a Kjellin induction furnace; but, as no report of such tests has been made other than that by Rowlands, above cited, it may be assumed that the operation of the furnace on those alloys was found impractical.

ROECHLING-RODENHAUSER TYPE.

The Baltimore Copper Smelting and Rolling Co. tried several years ago to use an induction furnace of the Roechling-Rodenhauser type for making brass, the idea being to run in molten copper from a fuel-fired furnace, add zinc, and put in enough power to hold the alloy molten for pouring. The main purpose was to make a heated mixer rather than a melting furnace. It was thought that so little heat would have to be added that enough power could be put in without the current density exceeding that which would cause rupture. Various troubles with the furnace caused the abandonment of the idea before the experiments had gone far enough to show whether the pinch force would make the furnace inoperable.

Vom Baur⁷⁴ says that he has been told that brass has been melted at the Roechling Eisen und Stahlwerke, in a three-phase Roechling-Rodenhauser furnace, using pole plates,⁷⁵ without interference from pinch troubles.

On the other hand, Dr. K. G. Frank, formerly American agent for Siemens and Halske, in response to an inquiry, informed one of

⁷² Rowlands, T., Induction furnace progress, *Trans. Am. Electrochem. Soc.*, vol. 17, 1910, p. 103.

⁷³ Arnold, J. O., Department of nonferrous metallurgy at Sheffield University, Eng. Supp. *Lancet*, Third, Oct. 26, 1910. *Jour. Soc. Chem. Ind.*, vol. 29, 1910, p. 1254.

⁷⁴ Vom Baur, C. H., Personal communication.

⁷⁵ See Rodenhauser, W., and Schoenawa, J., *Trans. by vom Baur, C. H., Electric furnaces in the iron and steel industry*, 1917, p. 215.

the writers in 1915 that the induction furnace then being made by Siemens and Halske as a combination of the Roechling-Rodenhauser, Frick, and Kjellin induction furnaces, was not deemed suitable for brass because of troubles from the pinch force. This statement appears to cover the present situation of the horizontal ring induction furnace.

HOWARD FURNACE.

Howard⁷⁶ suggests a furnace designed for melting copper, brass, and aluminum, in which a shallow bath of metal forms part of the secondary of an induction furnace, the rest of the secondary being a heavy U of conducting material, as of copper, placed below the bath, each leg of the U having a tip of graphite or of water-cooled steel which makes contact with the bath. The loss of heat in such a solid portion of the secondary would be terrific, and it is very doubtful if a furnace so constructed could be made to operate at all.

HERING FURNACE.

Having discovered that the pinch force spoiled all possibility of the ordinary induction furnace being made to operate on brass, Hering set to work to tame this force and to utilize it in the construction of a brass furnace. By opposing the pinch force with a sufficient hydraulic head of molten metal, it is obvious that the metal can be kept from rupturing. Hering found that not only was this the case, but that if the bottom of the tube containing the molten resistor was closed by a solid material, the pinch force caused the tube to act as a pump, drawing cool molten metal down the outside of the tube, heating it by its own resistance, and ejecting it up the center of the tube. This squirting action produces a little fountain of molten metal that is continually taking in cool metal and throwing out hotter metal. All the heating is done in the tube, but it is possible to heat up a large volume of metal because of the circulation.

The Hering furnace has been fully described in the literature.⁷⁷

⁷⁶ Howard, L. E., U. S. Patent 1,076,887, Oct. 28, 1913.

⁷⁷ Hering, C., U. S. Patents 988,936, Apr. 9, 1911; 999,720, Aug. 1, 1914; 1,105,656, Aug. 4, 1914; A new type of electric furnace: *Trans. Am. Electrochem. Soc.*, vol. 19, 1911, p. 255; Electric furnaces for molten materials: *Met. and Chem. Eng.*, vol. 9, 1911, p. 371; Ideals and limitations in the melting of nonferrous metals: *Jour. Inst. Metals (British)*, vol. 17, 1907, p. 243; Advantages of a small high-speed electric furnace: *Met. and Chem. Eng.*, vol. 11, 1913, p. 183; Possible reduction in the power consumption in electric steel-refining furnaces: *Met. and Chem. Eng.*, vol. 9, 1911, p. 590; Clamer, G. H., The Hering electric furnace for commercial brass melting: *Trans. Am. Inst. Metals*, vol. 7, 1913, p. 350; Clamer, G. H., and Hering, C., Electric brass melting: *Trans. Am. Inst. Metals*, vol. 8, 1914, p. 270; The electric furnace for brass melting: *Trans. Am. Inst. Metals*, vol. 6, 1912, p. 95; Lyon, D. A., and Keeney, R. M., Electric furnaces for making iron and steel: *Bull. 67, Bureau of Mines*, 1916, p. 87; see also *Elektrochemische Werke*, German Patent 309,973 of Dec. 8, 1915.

After development on a laboratory scale, the furnace was built on a commercial scale, with a total capacity of about 1,500 pounds, of which 500 to 750 pounds was retained from one heat to another. Furnaces were tried out by the National Cash Register Co., the Scoville Manufacturing Co., and the Ajax Metal Co. The first of these large furnaces, that at the National Cash Register Co., was tried out on April 30, 1914, one of the writers being present. There appeared various transformer and other troubles incident to the design of a large furnace of a new type previously operated only in

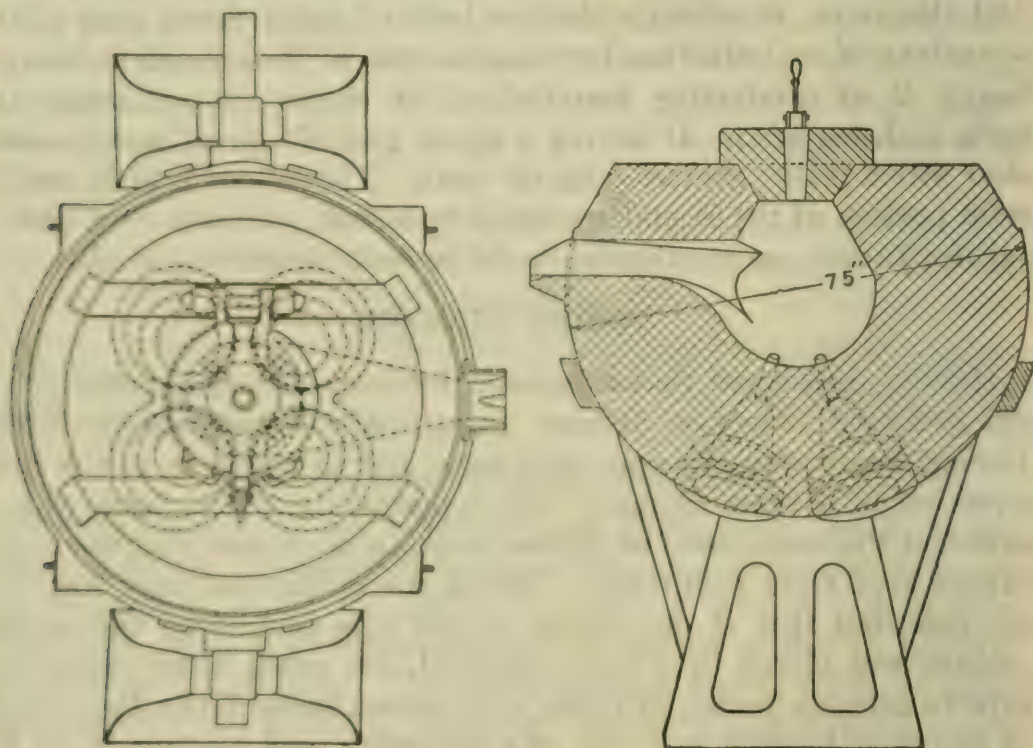


FIGURE 34.—Plan and elevation of Hering resistance furnace.

a much smaller size, so that the furnace could not be made to melt metal at that time. Some further work was done with it, but it did not do any commercial melting.

The furnace at the plant of the Scoville Manufacturing Co. melted a good deal of metal, but was finally discarded. The results of the tests at that plant are not available, save that the metal loss on yellow brass was well under 2 per cent, and a loss of one-half of 1 per cent was considered attainable.

The furnace at the Ajax-Metal Co., shown in figure 34 and Plate XXI, *B*, (p. 235) was operated commercially for some time. One of the writers was present in December, 1914, while this furnace was in operation. The furnace was built in the shell of a Schwartz open-flame furnace, which was approximately spherical and about 6 feet in diameter. The lining was about 18 inches thick and consisted of fire brick with an inner rammed lining of high temperature asbestos cement. Inasmuch as the resistor tubes can not operate unless they

are filled with molten metal, the furnace must be started by pouring in enough molten metal to fill the tubes and provide also sufficient hydraulic head to oppose successfully the pinch force. In order to preheat the empty furnace when starting up, and to prevent freezing to the starting charge of molten metal, the oil burners of the Schwartz furnace were left in place.

Inasmuch as the available power supply was two-phase, four-wire, four-resistor tubes were provided. These tubes were placed vertically in the bottom of the furnace and were formed by putting tubes made of the regular crucible mixture of graphite bonded with fire clay in place and ramming up the bottom around them. The electrodes themselves were heavy copper blocks set at the bottoms of the resistor tubes and were arranged to be water-cooled by a copious water supply. The electrodes were approximately 5 inches thick, and were in contact with the molten charge in the tubes above and with the cooling water below. The flow of cooling water had to be kept up in sufficient volume to prevent the copper blocks from melting into the charge, so that the molten charge could not run down into the water and produce a disastrous explosion.

It is obvious that a fin of metal entering a crack in the bottom of the hearth and extending from one electrode to another in the same phase would bridge across between the electrodes and short-circuit the current out of its proper path. The graphite fire-clay tubes were used to prevent this contingency, as they were less liable to crack than the lining itself. The whole bottom could not well be rammed up of crucible mixture, as it would itself conduct the current and would be likely to short-circuit it.

The cylindrical resistor tubes shown in figure 34, which were originally used, had been replaced at the time of the test by funnel-shaped resistors $1\frac{1}{2}$ inches diameter for the first $2\frac{1}{2}$ inches from the electrode and then flaring up from $1\frac{1}{8}$ inches diameter to $2\frac{1}{2}$ inches diameter at the hearth, which was 12 inches from the electrodes. These tubes allowed a freer circulation of metal than plain cylindrical tubes.

As only an extremely low voltage is required or can be used, the current carried is very heavy. The voltage drop per resistor tube was around 3 volts, the amperes per phase being around 11,000. It is on account of the high current and low voltage required that carbon or graphite electrodes could not be used; had they been used, their resistance would have been so great in comparison to the resistance of the resistor that the heat would have been generated mainly in them instead of in the tubes. The water-cooled copper electrodes were therefore inevitable.

These heavy currents made it imperative for the leads from the low voltage transformer to be very short in order to avoid heat losses in them and to avoid a low power factor. The transformer was

therefore built integral with the furnace, being attached to the bottom of the furnace shell, and tilting with it when the furnace was tilted to pour.

The transformers were designed for a total power input of 120 kw., but could not be operated at more than 100 kw. without dangerous heating, even though they were regularly air cooled by blowing air on them by electric fans. The joints or connections in the secondary circuit between transformer terminals and the heavy leads going to the electrodes had to be packed with waste, and the waste wet with water every 15 minutes to prevent overheating of the joints. Some of the transformer difficulties might have been reduced by further experiments, but the design of a transformer for such low voltages and high currents, where lightness is desirable and where a high-power factor is needed, is a difficult problem. The transformer is essentially one of the weak points in a furnace of this design.

Before the test the furnace had been operated for two full days, 24 hours a day, and was therefore fully heated up. The material melted in the first part of the test was manganese bronze ingot, containing about 40 per cent zinc, the ingots weighing about 30 pounds each.

The furnace held about 1,500 pounds of metal, but only about 625 pounds, or one ladleful, was poured at a time, the rest being retained in the furnace. Zinc and aluminum to bring the ingot to the desired composition were added in the ladle.

In the test 15 heats of around 625 pounds and 2 heats of around 300 pounds, 9,978 pounds total, including ladle additions, were melted in 21 hours 20 minutes, continuous running, the output thus being about 450 pounds per hour. The power used was 1,797 kw. h., at the rate of 396 kw. h. per ton, the metal being poured at an average of 1,010° C. (1,850° F.). The average power input was 93 kw. The power factor averaged 80 per cent.

On the total run of manganese bronze ingots 25,257 pounds of clean metal were charged and 24,479 pounds of metal obtained. The skimmings contained 428 pounds of recoverable metal. The gross loss was thus 778 pounds, or 3.08 per cent, and the net loss 350 pounds, or 1.42 per cent. The furnace had been given a new rammed-up asbestos lining before this run, and there was doubtless some soakage into the hearth.

The circulation of the metal in the tubes was very rapid; when the metal level was low, after pouring, the surface of the molten metal over each tube was decidedly raised through the ejection of a stream of metal. By sticking the end of a pyrometer with a small tip on the protecting tube^{7*} into the resistor tubes, the temperature of the

^{7*} See Manning, Van, H., Year book of the Bureau of Mines for 1916: Bull. 141, Bureau of Mines, 1917, p. 106.

stream of molten metal coming out of the center of the tube was found to be only about 20° C. (35° F.) higher than that of the body of the melt.

After the run on manganese bronze ingot, the furnace was operated on "irony brass" during the visit of one of the writers. A bath of yellow brass was melted and then a charge was fed in consisting of yellow brass that could not be readily separated from the iron it contained. The charge included old alarm clocks with some brass wheels on steel axles, steel shotgun shells with brass heads, and flexible tubing with a steel inside and brass outside, which would normally be fed to a cupola and only the copper recovered.

The charge usually floated on the surface of the melt, and as soon as the brass had melted the iron and dirt was rabbled or skimmed out. Aside from dirt the charge was probably 70 per cent iron, which was, of course, heated up as well as the brass, and only about 30 per cent brass. This material had to be charged and the iron taken out continually; therefore the furnace could not be tightly closed, as it had been on the manganese bronze run, and the cover was open most of the time. Some zinc was thus lost by volatilization.

It took about $2\frac{1}{2}$ hours to melt 550 pounds of brass off of, say, 1,000 pounds of iron. The power consumption was about 800 kw. h. per ton of brass poured or 275 kw. h. per ton of junk charged. The temperature was kept down to about $1,010^{\circ}$ C. ($1,850^{\circ}$ F.) to minimize the solution of iron. The metal obtained contained nearly all the zinc of the original brass, and though it contained some dissolved iron, it was worth much more than the copper obtained by cupola melting would have been worth.

The power consumption in the manganese bronze run on 24-hour operation of about 400 kw. h. per ton, on an alloy heated only to $1,850^{\circ}$ F., was not as good as might be expected from a furnace generating heat within the metal itself, so that it was desirable to find out where the lost heat was escaping. There was no excessive loss of heat through the furnace walls, as the hand could be held on the shell after a week's steady operation. The furnace had been in steady operation for several days when the test was made, therefore no heat could be applied to heat storage in the walls. The only avenues for large loss were from the transformer and the electrodes.

It was necessary to keep a couple of electric fans blowing on the transformers and to keep wet waste on the connections between transformer taps and leads; a notable loss, which could not be measured, was evidently going on there. The greatest loss was in the cooling of the copper electrodes to keep them from melting.

By measuring the rate of flow of the electrode-cooling water and by taking the temperature of the incoming and outflowing water, it was found that, with the furnace operating at a little under 100

kw., $46\frac{1}{2}$ kw.—109.5 pounds water per minute, at 24° F. temperature rise—and $48\frac{1}{2}$ kw.—93.6 pounds water per minute, at $29\frac{1}{2}^{\circ}$ F. temperature rise—or an average of about $47\frac{1}{2}$ kw., was lost in the electrode-cooling water. As several kilowatts were evidently lost in the transformer, at least half the power supplied was used in heating air and water required to keep transformer and electrodes in operation, leaving the other half to heat the brass and the furnace.

The furnace melted 450 pounds per hour. At the theoretical figure taken by Clamer and Hering⁷⁹ for melting 2:1 brass, 6.9 kw. h. per 100 pounds, the power usefully applied to melting brass was 31 kw. The heat balance then was evidently about as follows:

TABLE 51.—*Heat balance of Hering furnace.*

Application of heat.	Kw.
Usefully employed in melting-----	31
Lost in cooling electrodes-----	$47\frac{1}{2}$
Lost in cooling transformer and leads, approximately-----	$5\frac{1}{2}$
Lost through radiation from furnace shell, approximately-----	16
Total-----	100

The Ajax Metal Co. made many attempts to improve the electrodes. Copper electrodes of various shapes were tried to no avail. Efforts were then made to utilize an electrode of higher melting point to require less water-cooling. Attempts were made to use steel electrodes with tips insoluble in brass, the tips being welded on or cast into the steel. Ferrochrome as a tip dissolved somewhat in the bath. Ferrotungsten did not, but gave trouble from cracking. The nearest approach to a satisfactory electrode was a tubular steel electrode with a graphite tip, but it did not last long, as the brass soon worked back of the graphite. Even with this change, 25 per cent of the power supplied was lost in the cooling water and the best figures on power consumption were 360 to 335 kw. h. per ton on continuous operation. Continual trouble was met through cracking of the furnace bottom and the seeping-in of metal, forming fins that sooner or later short-circuited the electrodes.

After long and patient experimental work the Hering furnace was abandoned by the National Cash Register Co., the Scoville Manufacturing Co., and the Ajax Metal Co., and has not since been tried out further. No other electric furnace suggested for brass melting that is not now in commercial use had such a thorough trial as the Hering.

Dr. Hering is understood to contemplate the test of a modification of his furnace, designed especially for steel, in which the furnace is

⁷⁹ Clamer, G. H., and Hering, C., The electric furnace for brass melting; Trans. Am. Inst. Metals, vol. 6, 1912, p. 35.

to have two hearths connected by a refractory wall in which is provided a hole connecting the hearths, the molten metal in this hole acting as the resistor. The low-voltage current is to be led into each hearth by many relatively small wires or rods—of iron for a steel furnace, of copper for a brass furnace. Whether thus subdividing the electrodes and embedding them in the refractory end walls of the furnace will allow operation without excessive heat loss can only be determined by trial.

Quesneau⁸⁰ has suggested a furnace in which the pinch effect was allowed to make and break the circuit continually in a resistor tube, the heating being done either wholly by the resistance heating in the tube or by having such a tube in the same circuit with an arc in order to stir the charge. These furnaces unquestionably never ran, for all experience shows that a furnace in which the pinch force is causing continual disruption of the current refuses to take enough power to do work and becomes inoperable; moreover, it is entirely out of the question to combine an arc and a pinch-effect resistor in the same circuit, as the current and voltage requirements of the two are widely different.

If some form of the pinch effect on a separate circuit could be utilized as an electromagnetic pump, not primarily as a source of heat, to stir the metal in a direct or indirect arc furnace, it might serve to decrease surface overheating; but no satisfactory form has been suggested, and other means of stirring appear cheaper and more convenient.

The main trouble with the Hering furnace, then, lies in the use of solid electrodes which have to be water-cooled to keep them solid and, in this water-cooling, use too much power. The next step obviously is to eliminate the electrodes by joining two resistor tubes together and by making them form the secondary of an induction furnace with the metal in the hearth, but retaining the use of the hydraulic head of the molten charge to oppose the pinch force and prevent rupture.

This suggested change brings the design to that of a vertical ring induction furnace that may be visualized by thinking of a signet ring with the signet held uppermost. The signet represents the body or hearth of the furnace, which contains the bulk of the charge, while the circlet of the ring forms the resistor loop or secondary of the induction furnace. The loop may, of course, be at any angle or of any shape as long as it is below the body of the bath, that hydraulic head may oppose the pinch force.

⁸⁰ Quesneau, A. L. J., U. S. Pat. 948,343, Feb. 8, 1910. A new electric steel furnace, Trans. Am. Electrochem. Soc., vol. 17, 1910, p. 131.

VERTICAL RING INDUCTION FURNACE.

Various forms of vertical ring induction furnaces have been suggested, and a few of them tried out, for melting steel, or for use in the hearth of a furnace for ore reduction, but melting brass in them was not suggested when they were brought out. Schneider⁸¹ first described a furnace of this type, the patent description being fairly simple and closely allied to later successful forms of this type. The Schneider furnace was built and tested at the Creusot works in France in a rather more complicated form. Guillet⁸² states that the circulation in the inclined resistor channels of the Schneider furnace was very rapid and ascribes it to the difference in density between hot and cool metal. The writers have experimented with copper and brass contained in tubular containers like those of the Hering furnace, highly heated at the bottom and comparatively cool at the top. The heat was developed outside the containers and not in the metal itself in order to eliminate pinch effect and to leave only the thermal circulation. The motion could hardly be noted and was not in the least comparable to the violent motion in a resistor in which the pinch force is acting. It is plain that circulation due to pinch force was obtained in the original Schneider furnace, though it was not recognized as such at the time. The idea that circulation was caused by differences in the density was taken up by Gin,⁸³ who designed a furnace, with the cooperation of Schneider, in which two hearths were connected by tubes below the metal level, but it does not appear to have had much, if any, commercial success. There have been some later developments of this type for steel melting, since a Saladin-Schneider is listed among induction furnaces, presumably operating according to a recent article by Escard.⁸⁴

The rights to the Schneider patents for the United States have been purchased by the Ajax Metal Co.

German patents to Wallin⁸⁵ and to Vereinigte chemisch-metallurgische und metallographische Laboratorien⁸⁶ describe modifications of the vertical-ring idea, but do not appear to have been brought to any commercial application.

Snyder⁸⁷ patents a form of vertical ring induction furnace in which part of the ring may be a solid or liquid conductor, the fur-

⁸¹ Schneider, C. P., U. S. Pat. 761,920, June 7, 1904; 763,330, June 21, 1904; Clamer, G. H., Melting brass in the induction furnace; Jour. Am. Inst. Metals, vol. 11, 1917, p. 185.

⁸² Guillet, L., Les alliages metalliques, 1906, p. 70.

⁸³ Gin, G., U. S. Pat. 875,801, 1908. Electrometallurgy of the rare metals, Trans. Am. Electrochem. Soc., vol. 12, 1907. The self-circulating Gin furnace for the electric manufacture of steel, Trans. Am. Electrochem. Soc., vol. 15, 1909, p. 205.

⁸⁴ Escard, J., Induction furnaces for making steel, Rev. gen. Electricite, Dec. 13, 1919, abstracted in Iron Age, 1920, p. 606.

⁸⁵ Wallin, N., German Patent 183,622, Mar. 4, 1907, application Oct. 9, 1904.

⁸⁶ Vereinigte chemisch-metallurgische und metallographische Laboratorien, G. m. b. H., in Berlin, German Patent 224,577, Aug. 3, 1910, application Nov. 27, 1907.

⁸⁷ Snyder, F. L., U. S. Patents 825,359, July 10, 1906; 859,134, 859,137, July 2, 1907.

nace being designed for smelting zinc. Copper is mentioned as the material of the solid conductor, but it would be dissolved by molten zinc in contact with it.

Crafts⁸⁸ described a somewhat similar design. Neither the Snyder nor Crafts induction furnaces were designed for brass melting nor do they appear to have gotten to the commercial stage.

FOLEY FURNACE.

A single-phase vertical-ring induction furnace, intended for brass melting, was built by C. B. Foley⁸⁹ at the plant of the National Cash Register Co. in 1913-14, and the first attempt at running it was made on January 20, 1914, in the presence of one of the writers.

The furnace consisted of a hearth 5 inches wide, 14 inches long, 10 inches deep. Connecting with each end of the hearth was a segment, about 260°, of a circle of about 18 inches diameter. This segment had a circular cross section of 2 inches diameter. To provide a conducting secondary to start the furnace a copper ring, 1 inch in cross-sectional diameter, was placed inside a wooden ring, the outside diameter of whose cross section was 2 inches. This wooden ring was rammed up inside the furnace to form the secondary tube. The lining of bonded magnesite was rammed up inside the furnace shell above this wooden form and about another one in contact with the first to form the hearth. After the magnesite had dried the hearth form was removed, and the current turned on to heat the copper ring and to char the wood of the resistor form; then an air blast was turned onto the wood and the wood burned and blown out, leaving the 1-inch diameter copper ring loosely hanging in the 2-inch diameter secondary loop. One leg of the rectangular, laminated core on which the primary coils were wound passed through a hole in the center of the furnace, thus being within the resistor loop.

The first thing to find out about this type of furnace was whether there would be the same sort of circulation in the Foley resistor loop as in the Hering resistor tubes. Hitchcock⁹⁰ had stated that in order to get a circulation due to the pinch force there must be a solid end in such a resistor, and Hering⁹¹ had said that in a single resistor tube with two outlets there would be a squirting of the metal from both ends of the tube, but a stagnant place in the tube "where the metal would not be circulating, and hence would immediately overheat and vaporize."

In order to test this statement and to get some information out of the furnace before running the risk of spoiling it by trying to use

⁸⁸ Crafts, W. N., U. S. Patents, 1,069,923, 1,069,924, Oct. 12, 1913; 1,070,017, Aug. 12, 1913.

⁸⁹ Foley, C. B., English Patent 114,853 of Apr. 13, 1916.

⁹⁰ Hitchcock, H. K., Discussion, Trans. Am. Electrochem. Soc., vol. 19, 1911, p. 267.

⁹¹ Hering, C., Discussion, Trans. Am. Electrochem. Soc., vol. 19, 1911, p. 269.

it on brass, it was decided to run on lead and to see whether the circulation desired was obtained. So the copper ring was brought to redness and the lead was fed in. The furnace took 8 to $8\frac{1}{2}$ kw. with a primary voltage of 450 to 460 and an amperage of 41 to 44, the power factor being 23 per cent. One of the four primary coils was then cut out, the primary voltage being then 458, amperage 76, the kw. 17.4, and the power factor 50 per cent.

As soon as enough lead had been melted by the hot copper ring to fill the vacant space in the resistor tube and to establish the connection of molten lead in the hearth between the ends of the resistor tube, a violent circulation was set up, a little fountain of lead being formed over each opening into the resistor tube, just like the action of the Hering resistor tubes in small Hering furnaces that had been seen working on lead. The pumping of the lead out of the resistor was violent enough to force out or float out the nails that had been used in fastening the wooden form used for the resistor tube in the rammed-up lining.

In 13 minutes the furnace melted and raised to 525° C., 102 pounds of lead, the furnace operating at an average of 17.5 kw., using 3.8 kw. h. and having a power factor of 58.

The furnace had not been provided with a tilting mechanism, so some of the lead was ladled out, but the resistor tube was left filled with it and the current was cut off, the lead freezing in the tube.

On turning on the current and melting the solid lead it was found that a crack had been made in the magnesite lining, as lead began to drip out at one point. The leak was plugged up and the run continued. About 203 pounds solid lead left in the furnace was melted and raised to 425° C. in 40 minutes, using 12.5 kw. h. One hundred and three pounds more lead was then charged, melted and raised to 425° C. in $11\frac{1}{2}$ minutes, using 3.5 kw. h.

The lead was again ladled out down to the copper ring and an attempt made to melt the ring. Before it melted, however, it became soft, and a piece broke out, thus breaking the secondary circuit. About 50 pounds of molten red brass was poured in to restore the circuit, and as the furnace was only taking 17 to 18 kw., another of the primary coils was cut out. The furnace then took 43 kw. at 440 volts, 163 amperes on the primary, or a power factor of 73. The copper ring melted and the furnace operated for a few moments on an alloy made up of lead, copper, and red brass; that is, it might be considered a heavily leaded red brass. The circulation with brass was the same as had been shown with lead, and nothing out of the way occurred that could be ascribed to a "dead spot" in the resistor.

The leak that had been successfully plugged when lead only was melted began again and the furnace could no longer be operated.

The run had indicated, however, that a pinch-force circulation could be obtained in a vertical-ring induction furnace. It had also shown that a charge should not be allowed to freeze in the resistor tube of such a furnace.

Work on the Foley furnace was not carried further at the National Cash Register Co., but was later resumed at the plant of the Bristol Brass Co. In March, 1917, one of the writers visited this plant and saw a 60-kw. furnace of about 1,000-pound capacity, capable of pouring some 700 pounds per heat. The furnace was not in operation, as it was undergoing alteration. Material was on hand for three larger furnaces of about 3,000 pounds capacity, but construction had not been started.

The experimental furnace had, at that time, a secondary in the form of a flat tube, about 6 inches wide by three-fourths inch thick instead of the circular one of the first furnace, the change being made to cut down magnesite leakage. The resistor loop is circular, not having the sharp angle of the loop in the Ajax-Wyatt furnace, which will be described later. The resistor is made by ramming up two large blocks from a mixture of ground old crucibles, bonded with fire clay and water glass. These blocks are allowed to dry slowly and a depression corresponding to half the resistor loop is cut in each. Cement is put on the faces of the two blocks and the two put together, thus completing the casing of the resistor loop. The two halves of the casing are held together in a heavy iron frame and tightly squeezed by screwing the frame together. The assembled casing is then similarly cemented and fastened tightly to the hearth by rods and turnbuckles, thus assembling the furnace. The hearth has a brick lining, with thick walls, about 15 inches being used.

The furnace at this time had a power factor of only 58, owing largely to the distance between secondary loop and core, this distance being about 8 inches—5 inches of refractory and 3 inches of air space. Water cooling of the refractory walls within the secondary and outside the core has since been introduced, and should allow cutting down this space and therefore lower somewhat the magnetic leakage and raise the power factor.

This furnace was built to take 2,300 volts direct on the furnace primary, which the writers consider unsafe. Mr. Foley states that he can use 220 or 440 volts just as well, as 2,300-volt furnace being so designed to save the cost of a transformer for stepping down from that voltage to whatever voltage is chosen for the furnace primary.

The furnace was designed to pour through a tap hole from beneath the surface of the metal, the flow being controlled by a graphite plug. It was mounted on a wheel-and-track system for pouring direct into molds.

No detailed data on actual operation of the Foley furnace are available, though some melting has been done. A power consump-

tion of 225 kw. h. per ton on 70:30 brass is claimed, this being taken with the furnace hot, as it would be in 24-hour operation.

A copper ring is put into the resistor loop when the furnace is assembled and in starting up this is heated by the current and zinc or fed in till the loop is filled, or molten zinc is poured in; then brass, and, finally, copper are fed in till the charge has the desired composition.

In February, 1918, Mr. Foley offered to install for a prospective customer a single-phase 125-kw. furnace, capable of melting 1,000 pounds of yellow brass per hour at not over 250 kw. h. per ton on continuous operation. In fact, it was stated that pure copper could be melted at that rate, and that it was possible to hold the metal molten over night when working one shift only, with a power input of 12.5 kw. The primary voltage would be 220 or 440, as desired, the secondary voltage 8 to 10. No statement was made as to power factor, save that it was "high." The life of the lining on continuous 24-hour operation was said to be 2,000 heats, or 1,000 tons. The same furnace is said to be applicable to brass, bronze, and aluminum. There are no data available on actual runs in this furnace to show whether the figures given the prospective customer have or have not been attained in actual operation. The Bristol Brass Co., at whose plant most of the experimental work on the Foley furnace has been carried out, stated²⁴ that the furnace was not yet on a truly commercial basis. Nothing has been heard as to any later development.

Brophy²⁵ has patented a still different form of vertical ring induction furnace, but no actual application of it is known.

AJAX-WYATT FURNACE.

The only vertical ring induction furnace in wide commercial use in brass melting is the Ajax-Wyatt, developed by G. H. Clamer and J. R. Wyatt, of the Ajax Metal Co., after their experience with the Hering furnace had shown that a furnace with the metal circulation of the Hering was desirable, but that the electrode losses of the Hering should be eliminated. It has been the result of a long series of painstaking experiments. The first commercial Ajax-Wyatt furnace is shown in Plate XXI, A, p. 235. The 30-kw. furnace had almost its present form in October, 1915, and the 60-kw. in the summer of 1917. Though the furnaces were in constant use at the plant of the Ajax Metal Co., and a number were supplied to several other firms desiring to get an early start in the use of the furnaces, it was not until the fall of 1919,²⁶ by which time the design of the furnace had

²⁴Cartmell, Wm., Personal communication, Jan. 22, 1920.

²⁵Brophy, O. U. S. Patent 1,756,752, Mar. 11, 1919.

²⁶Metal Ind., vol. 17, November, 1919, p. v. See also 60 Ajax-Wyatts in operation. *Eastern of Electric Furnace Industry*, *Elect. World*, vol. 75, 1920, p. 161.

been standardized and full information collected on its behavior, that the furnace was advertised for general sale. The conservative attitude of the designers of this furnace is shown also by their frank acceptance of the limitations of this type and their refusal to supply it for use under conditions to which it is not fitted.

The Ajax-Wyatt furnace has been described by Wyatt,⁹⁵ Clamer,⁹⁶ Blakeslee,⁹⁷ and Kenyon.⁹⁸ It is built under the Wyatt patents under licenses as to the Schneider, Kjellin, and Hering patents.⁹⁹

To produce circulation of the metal, this furnace utilizes not only a slight amount of thermal or gravity circulation, due to heating the metal from the bottom, and some "pinch" force, due to the high current used, some 10,000 amperes at about 4 volts, in the secondary of the 30 to 40 kw. size and at about 6 in the 60-kw., but also a "motor" force.¹ This latter force is due to the attraction or repulsion between two conductors respectively carrying current in the same or in opposite directions. The "pinch" force in any conductor is due to the current in any single part of that conductor alone; the motor force is due alone to the current in another conductor or to another part or branch of the same conductor. When the conductors are molten the motor force causes a flow of the molten material.

By using a conductor with two branches at an acute angle with each other the circulation due to motor force can be made great and can be made to supplement or reinforce, instead of opposing, the circulation due to the "pinch" force.

The secondary of the Ajax-Wyatt vertical ring induction furnace is made in the general shape of an equilateral triangle instead of in that of a semicircle and is shown diagrammatically in figure 35. By this form circulation is obtained by a combination of three forces—gravity (heated metal rising), "pinch" force (as in the Hering furnace), and motor force. The circulation set up is very great, and the motion of the metal appears to facilitate the separa-

⁹⁵ Wyatt, J. R., U. S. Patents 1,201,671, Oct. 17, 1916; 1,235,628, 1,235,629, 1,235,630, Aug. 7, 1917; 1,312,069, Aug. 19, 1919; 1,313,571, Aug. 5, 1919.

⁹⁶ Clamer, G. H., Melting brass in the induction furnace, *Jour. Am. Inst. Metals*, vol. 11, 1917, p. 381. Ajax-Wyatt electric furnace, *Metal Ind.*, vol. 17, 1919, p. 362. The induction electric furnace, *Jour. Franklin Inst.*, vol. 190, 1920, p. 473. *Brass World*, vol. 16, 1920, p. 337, vol. 17, 1921, pp. 3, 36.

⁹⁷ Blakeslee, R. N., jr., Operating brass-making induction furnaces, *Elect. World*, vol. 74, 1919, p. 642.

⁹⁸ Kenyon, O. A., Developments in brass melting, *Iron Age*, vol. 105, 1920, pp. 819, 880; *Brass World*, vol. 16, 1920, p. 87.

⁹⁹ Kjellin, F. A., U. S. Patent 682,088, Sept. 3, 1901; Schneider, C. P. E., U. S. Patents 761,920, June 7, 1904, and 763,330, June 21, 1904; Hering, C., U. S. Patent 988,936, Apr. 4, 1911.

¹ Northrup, E. F., Nature and explanation of the motor effect in the Ajax-Wyatt furnace: *Jour. Franklin Inst.*, vol. 190, 1920, p. 817.

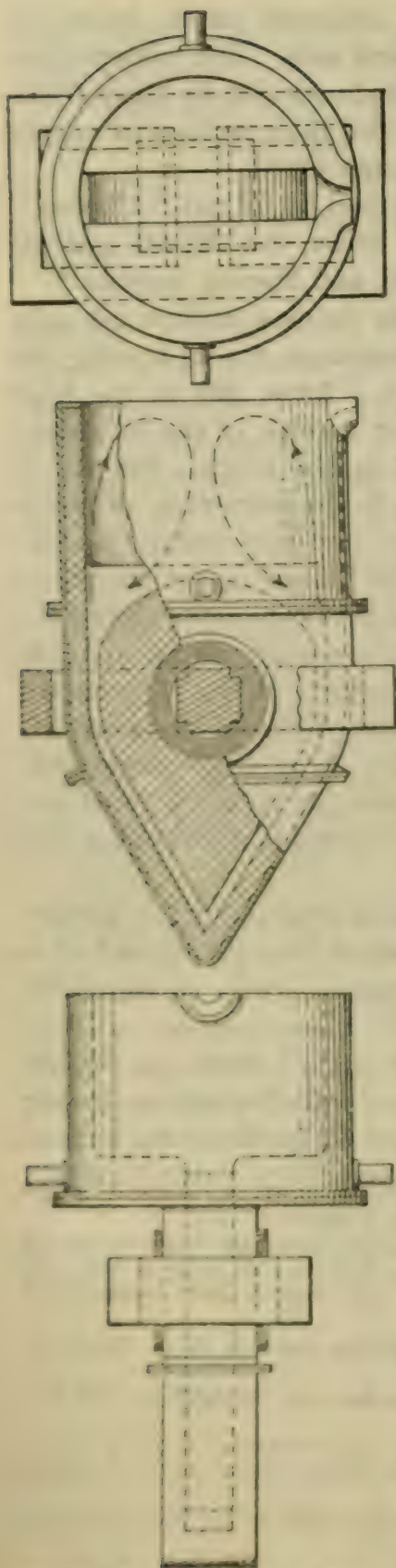


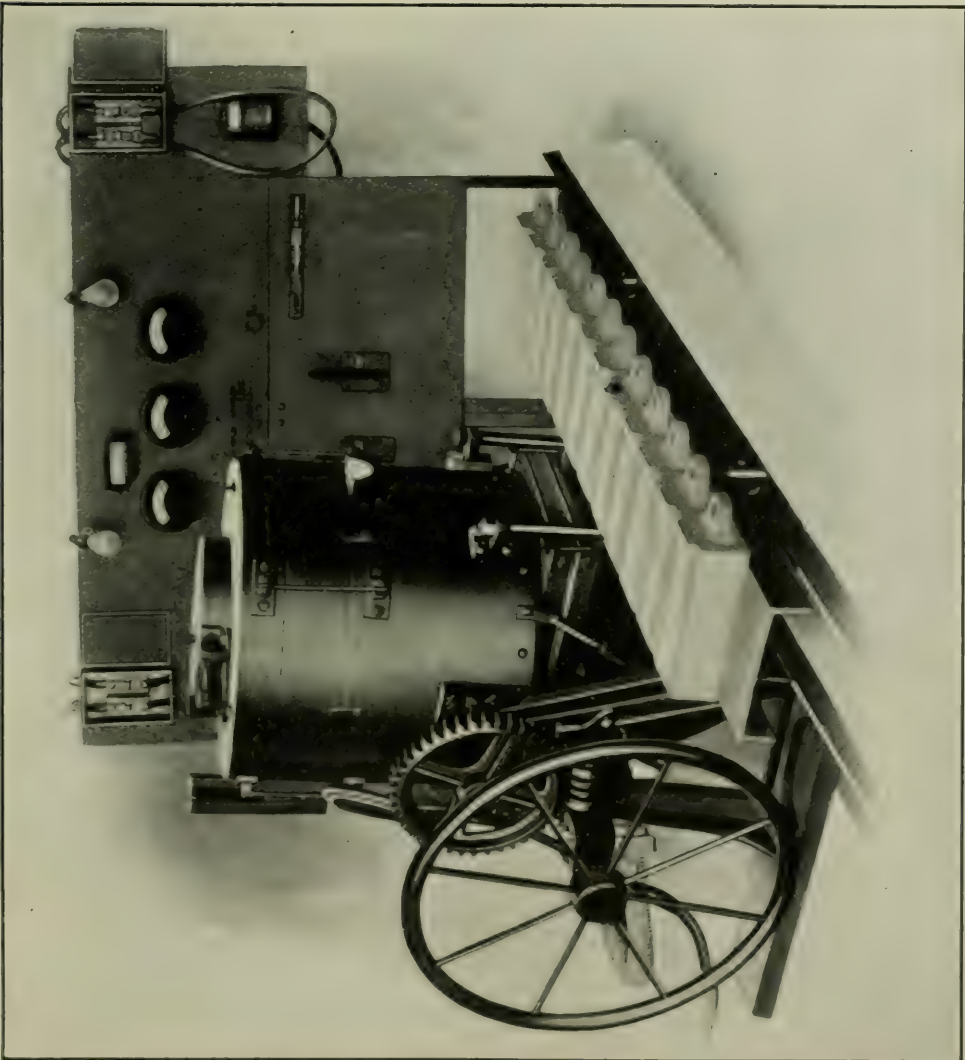
FIGURE 35.—Diagram of Ajax-Wyatt furnace.

tion of foreign particles such as dirt, dross, and oxide, and hence to produce clean metal.

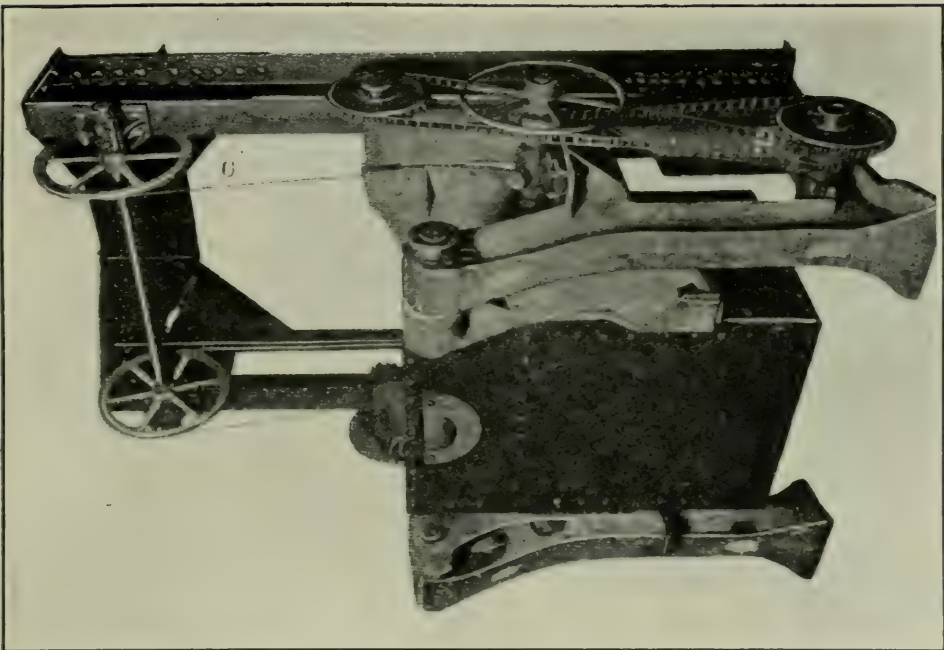
The furnace is designed to avoid the low-power factor common to horizontal-ring induction furnaces. The resistor loop or triangle has, in a 30-kw. size, a cross section of about $3\frac{5}{8}$ by $\frac{5}{8}$ inches, being made thin and flat to inclose as many lines of force as possible and to avoid magnetic leakage. The laminated iron transformer core of the furnace is built in $\square\square$ shape, as shown in figure 35, the primary coil, of flat copper insulated by asbestos tape, being wound about the central leg, and thus largely inclosed by the secondary loop. The core and primary are inclosed in a brass or other nonmagnetic casing, air from a small motor-driven blower being led into this casing to cool the core and the primary. There is no water cooling of any part of the furnace.

The 30-kw. size uses 220-volt, 60-cycle current at about 200 amperes on the primary, and forms a step-down transformer of a ratio of about 55 to 1, the secondary voltage being about 4, the amperage about 10,000, and the power factor, on 60-cycle current, above 80.

The 60-kw. furnace also has a power factor of about 80. It is calculated that 80 kw. is as high a power as a single loop can take on brass without having the power factor fall below 70. To construct furnaces of such large capacity that more power is required, it will be necessary to go to polyphase operation. A furnace with two or three secondary loops attached to the same hearth could thus be built to take at least 140 kw., at a 70 per cent power factor; such a



A. A 60-KW. TRUNNION-TYPE AJAX-WYATT FURNACE.



B. AJAX-NORTHROP HIGH-FREQUENCY INDUCTION TILTING FURNACE; USED FOR MELTING SILVER AT THE PLANT OF HANDY & HARMON BRIDGEPORT, CONN.



BATTERY OF TRUNNION-TYPE AJAX-WYATT FURNACES AT THE PLANT OF THE BRIDGEPORT BRASS CO.

furnace would melt at least 1,250 pounds of yellow brass per hour. The furnace is so far in commercial use only in 30, 60, 75, and 80 kw. sizes, single-phase, but experimental work is now under way on larger polyphase types.

The furnace does not require so thick a lining to attain a good thermal efficiency as most of the other types do, because at no time is any part of the hearth raised to a temperature above that at which the metal is poured, as the heat is generated wholly in the metal itself. Even the resistor tubes, where the heat is generated, are probably not heated over 25° C. (45° F.) above the pouring temperature of the charge. The problem of refractories as far as resistance to fusion at working temperatures is therefore not difficult, although other factors as will be shown later make this less simple than it appears from the point of view of temperature alone.

The furnace is compact, occupies relatively little floor space, and like all other well-designed electric brass furnaces, is cool to work around. There is no waste space at all in the furnace, so that the wall radiation is at a minimum. The furnace can be tightly closed to prevent loss of zinc, and even if the cover were not tightly closed is of such a form that the heavy zinc vapor will tend to lie in it and not be continually forced out, as there will be no draft through the furnace as long as the pouring spout is plugged tight.

There is, however, no automatically reducing atmosphere in the furnace such as is found in all tightly closed electric brass furnaces using carbon or graphite electrodes or resistors. The furnace atmosphere is normally oxidizing, and it is necessary to maintain a good cover of charcoal over the metal to counteract this. On account of the oxidizing atmosphere there is a tendency for a crust of zinc oxide to form on the inside of the hearth at the top, and in order to prevent this from reducing the hearth capacity, it is necessary to chip it out with an air hammer and high speed steel tools every two or three days.

The furnace is built in two forms, one for ladle pouring, in which the furnace tilts on trunnions, as in Plate XXII, A, the other for pouring direct into molds, in which it tilts on the lip. A battery of trunnion-mounted furnaces, Plate XXIII, and a battery of lip-tilting furnaces, Plate XXIV, are used at the plant of the Bridgeport Brass Co.

Inasmuch as the power supply to the furnace depends on the resistance of the molten metal in the resistor loop, and as the resistance of a 60:40 brass and of pure copper, for example, are widely different, it is obvious that if the furnace is to be used for such different alloys, some means must be provided for varying the primary voltage, as by an autotransformer stepping down the high tension current, say of 2,300 or 6,600 volts to the furnace voltage of around 220

volts, by which the furnace voltage can be altered. By such means alloys of 90 copper, 10 zinc, or 60 copper, 40 zinc can be handled satisfactorily in the same furnace. Alloys above 90 per cent in copper have, however, so low a resistance that a resistor of smaller cross section than that supplied for use on alloys high in zinc would be required. It is more difficult to get a good power factor on the high copper alloys, and the furnace is in general not so well fitted for such use.

An even more important limitation lies in the fact that any short-circuiting of the resistor loop would be fatal, and any break-out which might allow molten metal to run down onto the primary coils or core would not only put the furnace out of commission but might damage parts of the furnace beyond repair. It is thus essential that the refractory forming the resistor loop be free from any tendency to crack and to allow fins of metal to penetrate it.

To meet these conditions, the resistor loop is made by ramming up a high-temperature asbestos cement, containing fire clay and asbestos, about a smooth triangular brass form the size and shape of the resistor loop to be made.

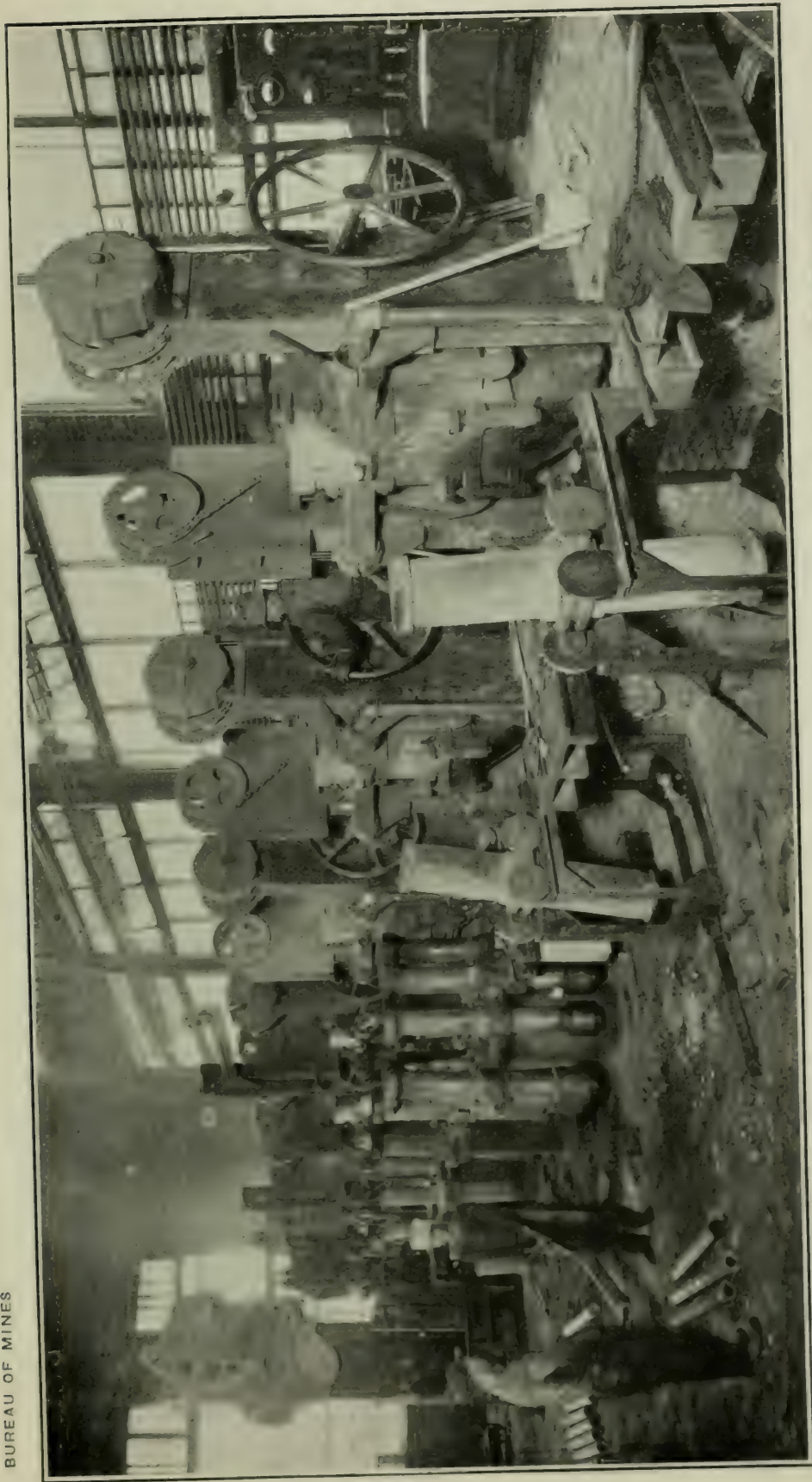
The furnace is dried out slowly in the air, then in an oven for several days, and finally gradually heated up to drive out all moisture and to set the cement firmly. The ramming and drying must be so well done that no cracks develop, and the operation requires skill and experience. Unless the work is properly done the life of the lining will be short.

The asbestos gives the lining sufficient flexibility to stand the expansion of the brass form without cracking. The brass form is left in, and when the furnace is assembled and ready to start a low voltage is impressed on the primary and the brass secondary gradually heated. Molten zinc is then fed in till the brass pattern has melted and the resistor tube is full of molten metal; brass and copper are then fed in till the charge has the desired composition.

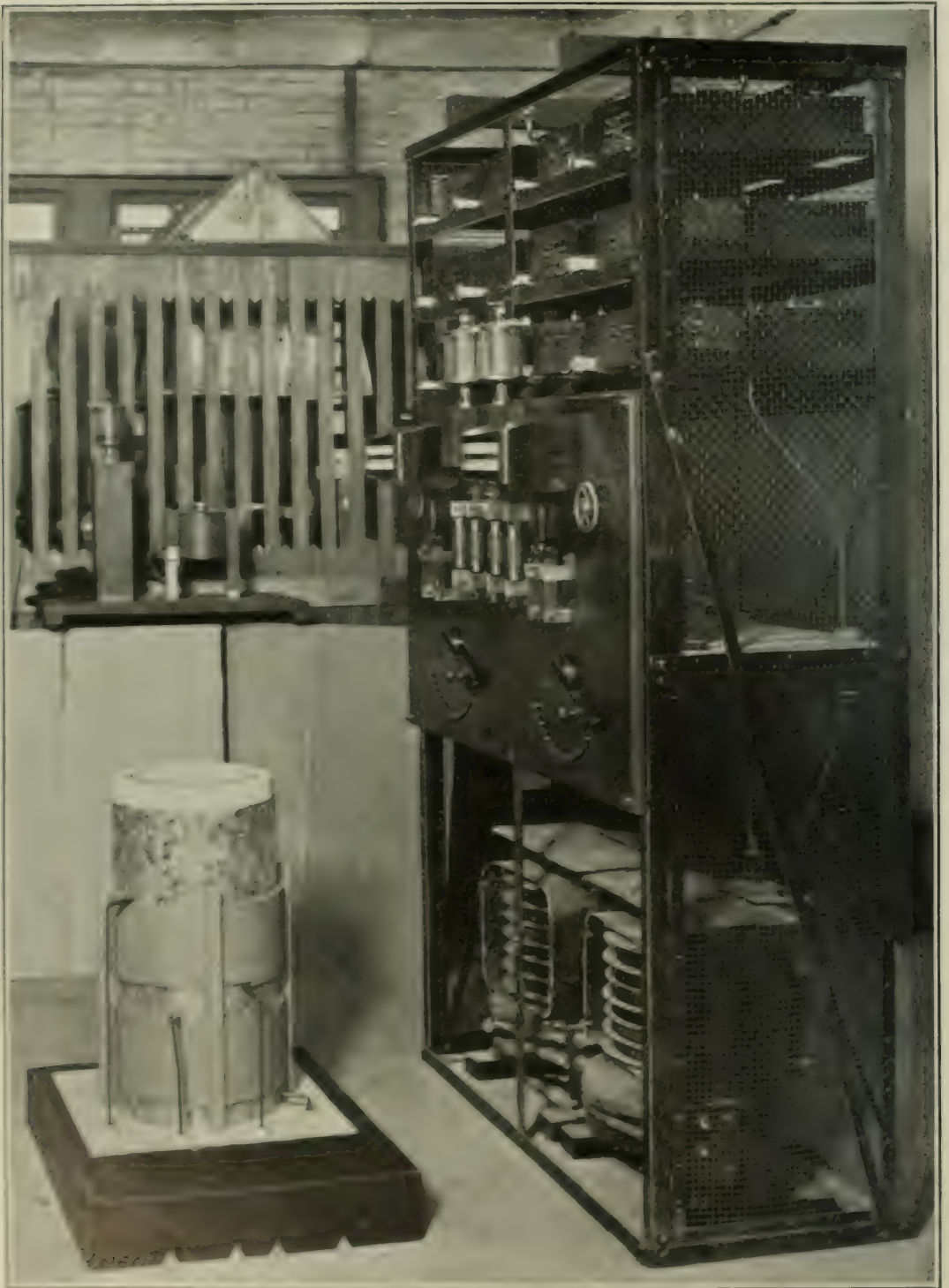
The asbestos cement lining withstands yellow brass successfully, the average life of a lining being 75 tons on the 30-kw. furnace, or 200 heats of 300 pounds, and as high as 375 tons or 2,500 heats has been obtained on individual linings. The cost of relining, including labor and materials, is given² as \$50 for the 40-kw. and \$75 for the 60-kw. size, at 1917 prices. Blakeslee³ gives it as "less than \$100" for the 30-kw. in 1919. The lining does not, however, so successfully withstand the action of alloys high in lead, which is notorious for its ability to soak through the pores of any refractory lining.

¹Chambers, G. H., Melting brass in the induction furnace, Jour. Am. Inst. Metals, vol. 11, 1915, p. 281.

²Blakeslee, R. S., Jr., Operating brass making induction furnaces, Elect. World, vol. 74, 1919, p. 642.



BATTERY OF LIP-POURING AJAX-WYATT FURNACES AT THE PLANT OF THE BRIDGEPORT BRASS CO.



HIGH-FREQUENCY FURNACE AND ACCESSORIES AT THE
PHILADELPHIA MINT.

The makers do not advocate the furnace for alloys containing over 3 per cent to $3\frac{1}{2}$ per cent of lead. One firm reports, however, that a 30-kw. furnace, melting mainly borings from an alloy of about 60 per cent copper, 30 per cent zinc, 5 per cent tin, 5 per cent lead, gave lining lives of 62, 64, and 43 tons.

Since rolling mills seldom melt alloys containing over 3 per cent lead, extrusion metal being the only composition given by Wood,⁴ which contains more than that amount, the furnace is rather better fitted for the average work of a rolling mill than for that of a foundry making sand castings, as the average foundry must often handle mixtures rather high in lead. This limitation may ultimately be removed by further advances in knowledge of refractories.

POWER CONSUMPTION.

The Ajax-Wyatt is the most efficient electric brass furnace yet developed, in the economical use of power when operated 24 hours a day. Furnaces of other types are seldom very efficient in so small a size as 30 or 60 kw., but it is doubtful if any other type of furnace of whatever size can operate on yellow brass 24 hours a day with as low power consumption per ton of metal melted as the 60 or 80 kw. Ajax-Wyatt. This is thoroughly in accord with the theory, since the furnace has no waste space and generates all the heat in the metal itself. Its radiation losses are therefore small and unlike the Hering furnace it has no electrodes to draw away heat.

The 30-kw. furnace melts 70:30 yellow brass, poured at $1,065^{\circ}$ to $1,095^{\circ}$ C. ($1,950^{\circ}$ – $2,000^{\circ}$ F.) at a power consumption on 24-hour operation of something less than 250 kw. h. per ton as a grand average of figures obtained under average operating conditions in rolling mills. The figures vary from 200 to 300 kw. h. per ton, the lower figure being obtained on heavy, clean scrap and the higher on bulky, oily turnings, which have to be constantly poked down into the bath with the furnace cover open most of the time.

The 60-kw. furnace does better, averaging, perhaps, 200 kw. h. per ton. It has melted 60:40 and 2:1 brass at 174 to 180 kw. h. per ton. When the larger multiphase furnaces are perfected, it will probably be possible to average about 210 kw. h. per ton on yellow brass, 24-hour operation; and, under the most favorable conditions, to get down to 175 kw. h. per ton. As this represents an efficiency of about 85 per cent, based on the most probable figures for the power theoretically required, it is not likely that any other type of furnace, however improved, can melt at a lower-power consumption per ton than is possible in this type.

⁴ Wood, R. A., Brass rolling mill alloys, Jour. Am. Inst. Metals, vol. 11, 1917, p. 181.

On a test of one of the early low-powered Ajax-Wyatt furnaces, which one of the writers witnessed in January, 1916, the furnace taking only $22\frac{1}{2}$ kw., the following results were obtained.

A total of 1,190 pounds of yellow borings—62 per cent copper, 36½ per cent zinc, $1\frac{1}{2}$ per cent lead—poured at $1,010^{\circ}$ C. ($1,850^{\circ}$ F.) average were melted in $7\frac{1}{2}$ hours using 164 kw. h., at the rate of 280 kw. h. per ton.

On a week's run of these borings, which contained about 1 per cent oil and dirt, 94.2 per cent of the charge was recovered as ingot and large pieces of metal from the skimmings; 2.1 per cent was recovered by washing the skimmings, leaving a loss on the original charge of 3.7 per cent, or, deducting the nonmetallic, a net loss of 2.7 per cent. The best figures obtained on the same sort of charge in pit fires showed a loss on the original charge of 6 per cent, or 5 per cent net loss. This figure agrees with that recently given by the editor of *Metal Industry*, who declared⁵ that in melting turnings in a crucible, carefully pushing the turnings below the molten metal as fast as they are added, the volatilization loss is 5 per cent.

There was no apparent volatilization of zinc in this run, though there were formed considerable amounts of light, fluffy dross, which entangled much shot metal.

In a test made in 1917 on two of the first Ajax-Wyatt furnaces installed at the Bridgeport Brass Co., in 24-hour operation on extrusion metal of 60 per cent copper, 1.5 per cent lead, 38.5 per cent zinc, the charge consisting of two-thirds heavy scrap and one-third dirty, oily chips, sometimes carrying very large amounts of oil, up to 10 or 12 per cent, 157,399 pounds of metal was charged, 147,084 pounds ingots (93.5 per cent) were poured, and 3,952 (2.5 per cent) pounds metal were recovered from dross, making a total recovery of 96 per cent and an apparent loss of 4 per cent. Most of this loss was oil and non-metallic charged with the borings. In crucible practice on the same mixture $1\frac{1}{2}$ pounds extra zinc per 100 pounds of charge must be added to make up for volatilized zinc, while if more than one-half pound were added to the electrically melted charges the zinc in the product was too high.

The furnace, therefore, saves at least 1 per cent of the metal charged. Not only was the net metal loss lower than in the pit fires, but the amount of metal to be put through a recovery process was decreased, a given charge producing more metal as ingot when melted in the Ajax-Wyatt than when melted in crucibles.

The 157,399 pounds, 78.7 tons, charged used 16,888 kw. h., or 215 kw. h. per ton. On the basis of the 147,084 pounds, 73.5 tons, of ingots produced, the power consumption was 230 kw. h. per ton. The average

⁵ Reply to inquiry on melting losses, *Metal Industry*, vol. 17, 1919, p. 518.

output was 250 pounds per hour. On further use one furnace melted 100 tons and the other 125 tons before requiring relining. Negro helpers operated the furnaces and poured and shrunk the metal, obtaining as good results as skilled casters on the pit fires.

The Bridgeport Brass Co. is now melting all its metal electrically, has torn down the stacks of its pit fires, and is making an advertising campaign⁶ based on the uniform high quality of electrically melted metal. In one of these advertisements it is stated that the introduction of the electric furnace has been the greatest advance made in the brass industry in 140 years, since direct alloying superseded the calamine process. This firm has even advertised⁷ its reserve stock of crucibles for sale.

Blakeslee⁸ gave in 1919 the following figures for regular operation of a battery of Ajax-Wyatt furnaces at the Bridgeport Brass Co.:

Average power consumption per ton, yellow brass, 24-hour operation, was 250 kw. h., average net metal loss, 0.5 per cent. On a test run, $7\frac{3}{4}$ hours, a furnace gave the following averages:

Kilowatt input -----	37
Pounds output per hour -----	291
Pounds poured per kw. h. -----	9.63
	(or 208 kw. h. per ton)
Power factor -----	81.8

Blakeslee states that since all melting at this plant has been done electrically there has not been a single case of "brass shakes," and that there has been a reduction in the number of severe burns that formerly frequently occurred from the breaking of crucibles.

The furnace is said to give a well-mixed and uniform product. It is also stated that the ingot can be shrunk better when poured direct from the electric furnace than when poured from the crucibles. In the early test previously cited it was found that the better shrinking allowed making a much smaller crop, to cut off the piped top, than in crucible melting. This firm is now using some larger Ajax-Wyatt furnaces of 80-kw., 1,500-pound capacity, which give about 205 kw. h. per ton. The power factor of these was 60 to 65 during its early development, but it was hoped to improve this. The original lining of the first 80-kw. furnace was still in good shape after melting 995 tons. Attention has also been given by this firm⁹ to the design of a modification of the Ajax-Wyatt, in which heat may be supplied not only at the bottom of the hearth but at the top also by an arc, a re-

⁶ Rocking furnace, *Electrical World*, vol. 74, No. 3, July 19, 1919, front cover. Ajax furnace, *Electrical World*, vol. 74, No. 12, Sept. 20, 1919, p. 32. Removal of stack, *Electrical World*, No. 9, Aug. 30, 1919, p. 11; *Brass World*, March, 1920, p. 24.

⁷ Bridgeport Brass Co., *The Foundry*, p. 188, vol. 48, Apr. 1, 1920.

⁸ Blakeslee, R. N., jr., Operating brass making induction furnaces, *Elect. World*, vol. 74, 1919, p. 642.

⁹ Clark, W. R., U. S. Patents 1,328,712 and 1,328,713, Jan. 20, 1920; 1,370,632, Mar. 8, 1921.

sistor, or by fuel heating, as in the melting of oily borings and low grade, dirty scrap, a crust is apt to form, bridging over the hearth, and requiring excessive poking to submerge it into the bath, when the heating is from the bottom only. A design for preheating by means of fuel¹⁰ has also been suggested, but none of the modifications has been thoroughly tried out.

TESTS OF COMPLETE HEAT BALANCE.

Another interesting development in the work of the Bridgeport Brass Co. with the Ajax-Wyatt has been the making of a test to show the complete heat balance, along the lines of a boiler test. Unfortunately the results of this test have not been published, but it is stated that the energy actually absorbed by the metal agreed well with that determined by pouring the metal into a calorimeter. According to these figures it takes 137.5 calories per pound to heat brass of 61 per cent copper, 3 per cent lead, 36 per cent zinc, to 1,000° C. About 13.72 pounds would be melted per kw. h. at 100 per cent thermal efficiency, or 146 kw. h. per ton.

Richards¹¹ gives a figure for 65:35 brass at 1,000° C., equivalent to 136 kw. h. per ton, and for a 85:15 bronze at 1,050° C. he gives the same figure. Clamer and Hering¹² give 138 kw. h. per ton for 2:1 brass at 1,000° C. Hansen¹³ calculates that it takes 8,240 large calories, that is, 191 kw. h. per ton, to raise 100 pounds of copper to 1,300° C., 7,395 calories to raise 100 pounds of previously alloyed 80:20 brass to 1,100° C. 174 kw. h. per ton and 6,919 calories to raise 80 pounds copper plus 20 pounds zinc to 1,100° C., 161 kw. h. per ton, the last figure being lower than the one preceding it because of the heat of solution of zinc in copper. According to the probable specific heat of molten copper alloys it will probably take from 10 to 15 kw. h. per ton of brass or bronze extra for each extra 100° C. above the melting point to which the metal is raised. The experiments of the Bridgeport Brass Co. indicate that the figures given by Richards, on which electric furnace efficiencies have usually been calculated, are probably low. It seems likely that 150 kw. h. per ton for average yellow brass poured about 1,050° C. and 170 kw. h. per ton for average red brass poured at 1,200° C. are better figures for the theoretical power requirements.

In a 1917 test at one of the plants of the American Brass Co. it was found that on 100 heats of yellow brass the average analysis of the tops and bottoms of the ingots for copper showed a variation of only

¹⁰Clark, W. R. U. S. Patent 1,328,714, Jan. 20, 1920.

¹¹Richards, J. W., Electric power required to melt metals, *Trans. Am. Brass Founders Assn.*, vol. 4, 1910, p. 95.

¹²Clamer, C. H., and Hering, C., The electric furnace for brass melting, *Trans. Am. Inst. Metals*, vol. 5, 1912, p. 161.

¹³Hansen, C., Electric melting of copper and brass, *Trans. Am. Inst. Metals*, vol. 6, 1912, p. 112.

0.05 per cent. The slight variation that did exist was almost within the limits of analytical error, the top being higher in copper than the bottom as often as the reverse; that is, the mixing of the charge is perfect, owing to the stirring action of the moving metal. In crucible practice there is a considerable tendency for the composition of the top and bottom of an ingot to vary from incomplete mixing.

It is stated¹⁴ that at the American Brass Co. it has been found that 100 pounds of zinc charged into the 600-pound Ajax furnace is completely and thoroughly mixed in five minutes with no stirring whatever aside from that done by the furnace itself.

It is further stated that when the 60-kw. furnaces, of which this firm has 15 in operation in Waterbury, are operating steadily without delays or interferences they melt 2:1 brass at an average of 174 kw. h. per ton. Each 60-kw. furnace should then produce 6 to 7 tons of yellow brass in 24 hours. Some lining trouble has resulted from nonuniformity in the asbestos cement, and some linings have failed on the first heat. Some trouble has occurred from stoppage of the power supply just after charging, so that the metal froze and ruined the lining. Several furnaces are reported to be operating on linings that have run over 1,500 heats, and the high figure at the time of the report was 1,829—540 tons. With care and barring accidents it is expected to bring the average life up over 2,000 heats, or to over 600 tons' output per lining.

The American Brass Co. pours direct into the ingot molds, either from a nose-tilting furnace or by lifting the trunnion type by a crane. At the P. and F. Corbin plant of the American Hardware Co., New Britain, Conn., a 30-kw. Ajax-Wyatt furnace in 24-hour operation gave, melting an alloy of 60 per cent copper, 30 per cent zinc, 5 per cent tin, 5 per cent lead, the charge being mostly borings, on a run of about 170 tons, an average of 245 kw. h. per ton. It took 10 kw. to keep the furnace and the metal retained in the resistor loop molten hot overnight ready to start the next morning if the furnace was not operated on a continuous 24-hour basis. This heating can be done by using a special transformer for stepping down from the transmission voltage of 2,300 or of 6,600 to the 220 volts for which the furnace is usually designed, and by using a different tap on the transformer to a still lower voltage for the overnight heating.

It is of interest to see what the power consumption will be when the furnace is operated for various periods per day.

¹⁴ Bassett, W. H., Personal communication, Jan. 20, 1920.

TABLE 51.—*Power consumption in 30-kw. Ajax-Wyatt furnace under various schedules of operation.*

Period of operation.	Operating, kw. hours.	Idle kw. hours.	Total kw. hours.	Total out- put, tons.	Kw. h. per ton.
24-hour	(30 × 24)		= 820	3.3	250
12-hour	{ (30 × 16) + (10 × 8) }		= 560	2.2	255
10-hour	{ (30 × 10) + (10 × 14) }		= 440	1.35	325
9-hour	{ (30 × 9) + (10 × 15) }		= 420	1.2	350
8-hour	{ (30 × 8) + (10 × 16) }		= 400	1.1	365

It should be remembered that Table 52 is calculated, not for the best possible 24-hour operation, but on the basis of actual plant operation for long periods, and that it is for the 30-kw. size, not the more efficient 60-kw. size.

Collins¹⁴² compares the induction furnace on 8-hour operation with that of the larger General Electric furnace, which is far less efficient in the use of power. Though he is forced to concede that the induction furnace has the highest thermal efficiency of all types, he claims that the smaller size of the induction furnace must involve so much higher labor cost that the sum of the two factors, labor cost and power consumption, with power at 1 cent per kw. h., shows a balance in favor of the General Electric furnace on 8-hour operation. He assumes that the induction furnace metal is to be poured by means of hand ladles, and says that the induction furnace must be charged by hand, while the General Electric furnace can be mechanically charged. These assumptions need not be correct for all cases. In a rolling mill the metal from either furnace may either be poured direct into the molds or from a large ladle; and charging, it would appear to the writer, could be done mechanically into the induction furnace more readily than into the General Electric, because the charging door on the induction type is at the top of the furnace while that on the General Electric is at the side.

The Ajax-Wyatt furnace requires no more attention or control than does the General Electric, with all its elaborate automatic control devices, for the former requires no electrical control other than the pulling of a switch when it is desired to shut off the power.

After watching both types of furnace in operation it would appear to the writers that, under rolling-mill conditions, there is no justification for assuming a higher labor cost per ton with one furnace than with the other, for by staggering the operation, a couple of men could charge, operate, and pour several induction furnaces.

¹⁴² Collins, E. F., Melting of some nonferrous metals and their alloys in the electric furnace, Chem. and Met. Eng. vol. 21, 1919, p. 673.

If the furnaces are used more than 8 hours per day, or if power costs more than 1 cent per kw. h., the advantage assumed by Collins decreases. The advantage of 25 cents per ton in cost of power plus labor, which Collins assumes the General Electric at 400 kw. h. per ton has over the Ajax-Wyatt at 300 kw. h. per ton, on the 8-hour basis with power at 1 cent, is entirely wiped out if power costs $1\frac{1}{4}$ cents per kw. h. instead of 1 cent.

There is room for a good deal of difference of opinion as to the most economical size of furnace for rolling-mill use,¹⁵ as well as to whether or not metal should be poured direct from furnace to mold. The decisions involve a good many factors. If the plant must pour a large number of small ingots, involving a pause to shrink each ingot, there is less advantage in a large furnace than when a plant can dispose of the metal rapidly into a few large ingots. If direct pouring is employed, then the small furnace allows easier control of the stream of metal.

It must not be forgotten that in big furnaces in which the metal is not mixed, as it is by the Ajax-Wyatt's self-circulating resistor, or by rocking or rotating other furnaces, there is danger that a large charge will not be thoroughly mixed.

In a report made by the metallurgist of a large rolling mill, the vertical ring induction furnace and a reflected-heat furnace are compared. Based on his experiments at a copper refinery where after copper was melted and refined in a 10-ton reverberatory, zinc was introduced in order to form brass and to save remelting the copper, but in which though "vigorously and faithfully" stirred, there was a good deal of variation in copper content of the resulting brass—he does not believe that the reflected-heat furnace in a 1,500-pound size or larger would be satisfactory in making cartridge brass, on account of the necessity of stirring the large charge through the door with a long stirrer.

ADVANTAGES OF AJAX-WYATT FURNACE.

From the point of view of its electrical characteristics, the Ajax-Wyatt furnace is eminently satisfactory. There is practically no fluctuation whatever in the load, so that ordinary distributing transformers are satisfactory for stepping down from line to furnace voltage, as there are no surges. The furnace runs along without any electrical attention. When the metal in the resistor tube reaches the boiling point, and bubbles of zinc vapor begin to be released, the resistance rises and the ammeter needle starts to vibrate or "kick." This

¹⁵ Compare Hering, C., Advantages of small high speed electric furnaces, *Met. and Chem. Eng.*, vol. 11, 1913, p. 183.

means either that the whole charge is hot enough to pour, being analagous to the "jump" of an iron bar thrust into the crucible to serve as a "works pyrometer" on yellow brass, or else that the charge has bridged over in the hearth and needs poking down.

The advantages of the Ajax-Wyatt may then be summed up as follows: It is a compact furnace, requiring little floor space. It reduces the metal losses on alloys high in zinc. It is thermally the most efficient brass furnace known; that is, on 24-hour operation it requires the lowest kw. h. rate per ton. It mixes the metal perfectly. It uses no electrodes or resistor carbon and requires no water cooling. Its electrical characteristics make it a desirable electrical load. Its reliability is high and its lining cost per ton is low.

Its disadvantages are (1) that it must be operated 24 hours a day or else kept hot overnight by using enough power to keep the metal retained in the resistor-loop fluid, as a freeze-up inevitably ruins the resistor tube and makes relining necessary; (2) if it is to be shut down, all the metal must be drained out, and in starting up it must be thoroughly preheated, as by an oil or gas flame, and it must then be started by pouring in a charge that has been melted in another furnace. The retention from one heat to another of enough charge to fill the resistor and to make a connection in the hearth between both legs of the tube makes it difficult to change from one alloy to another, unless the charge is such that the retained metal can be worked into the composition of the next charge.

The furnace will not handle alloys very high in copper, nor can alloys of high lead content be handled with the present lining. Even 5 per cent lead will probably reduce the life of the lining considerably.

The furnace is obviously fitted then for use in a brass rolling mill, in which yellow brass is melted, and in which 24-hour, or at least 16-hour operation is possible and very common, and in which the perfect mixture given by the furnace is very desirable. There are rolling mills in which conditions are such that furnaces of larger capacity than the present commercial sizes of the Ajax-Wyatt are desirable. In general, however, the furnace is worthy of careful consideration by any rolling mill, and so far it holds first place in actual achievement in that class of work.

It is obviously not fitted for use in foundries that do not melt large tonnages of yellow brass, but that must often change the composition of the charges to any one furnace from heat to heat. It is not fitted for use on highly leaded mixtures or on alloys around 90 per cent copper. It begins to operate at a decided handicap when it can not be used at least 16 hours a day, therefore it can not be considered at all by the average jobbing shop.

Its field is on the high zinc end of the scale, being best adapted for just those alloys which the direct-arc and stationary indirect-arc furnaces can not handle.

Nearly any alloy made in the nonferrous industry can be satisfactorily melted in either an Ajax-Wyatt furnace or a stationary indirect-arc furnace, but neither furnace can operate satisfactorily on even occasional heats in the other's field. Hence there is still room for the more versatile furnaces like the reflected heat and the rocking types.

The prices of Ajax-Wyatt furnaces, complete, save for the transformer for stepping down from line voltage to 220 volts, were given on March 29, 1920, as follows, for the standard sizes: 40 kw., \$5,500; 50 kw., \$6,500; 80 kw., \$7,500.

AJAX-NORTHROP FURNACE.

One more furnace remains to be considered, which is potentially even more versatile than any other as it can be built in either a tilting or tapping, or in a crucible lift-out type, can melt any alloy and work almost equally well either 24 hours a day or only an hour or two. It is considered here instead of under crucible furnaces because the heat is generated in the metal itself and because, like the Hering and the Wyatt, it is a type which the Ajax Metal Co. has been instrumental in developing. This is a new type of furnace invented by Prof. E. F. Northrup, of Princeton University, in July, 1916, and developed with the aid of the Ajax Metal Co. The Northrup furnace, instead of using ordinary alternating current, uses a high-frequency current such as is used in the wireless telegraph. Ordinary alternating current has 60 cycles or alternations per second, and the frequency of the current used in the Northrup furnace is preferably of the order of 10,000 or more cycles per second. Conducting materials in proper position to receive the potential energy released by a high-frequency current may absorb this energy, and by their resistance to the flow of current generate heat within themselves.

The Northrup furnace is an induction furnace, the heat being generated in the charge without the use of any electrodes to carry the current, but, unlike the usual induction furnace, the secondary does not have to be in the shape of a ring or loop. The heating is analogous to that due to eddy or Foucault currents in a transformer core.

Guggenheim¹⁶ has suggested the use of eddy currents in an electric furnace, but no commercial development of his suggestion is known.

¹⁶ Guggenheim, S., U. S. Patent 1,157,691, Oct. 26, 1915.

Northrup¹⁵ has briefly described his furnace and has given an exhaustive, 89-page account¹⁸ of the theory and the mathematics involved.

The furnace itself as applied to brass or silver melting consists of a conducting container, such as graphite for the metal, which may be a crucible that can be lifted out, a stationary crucible, or other container for pouring by tilting, or a container with a tap-hole at the bottom. This container is surrounded by a heat-insulating refractory, and in small furnaces is made very thin in order to secure "close coupling" of the inductor or primary coil with the secondary, the conducting crucible lining and the charge of brass itself. Large furnaces may be able to use a thicker refractory, since the radius of the crucible to be heated should theoretically be three-fourths the radius of the inductor coil.

Wrapped closely about the outside of the refractory is the "inductor," or primary, a spiral conductor that can be made of a nickel-chromium alloy, or may be of copper tubing and cooled by a stream of water. To this inductor spiral are connected the leads, one at each end for single-phase or one at each end and one in the middle for two-phase, from the source of high frequency current.

This current source may be an ordinary alternating current stepped up to a high voltage, 5,000 to 8,000 volts, connected to a bank of condensers and a special form of gap, also invented by Northrup, forming a Tesla oscillatory current circuit. The gap consists of graphite over mercury, in an atmosphere of alcohol vapor, obtained by a flow of alcohol from an oil cup. The Tesla circuit method has been tried only up to 60 kw., and is thought to be applicable only up to about 100 kw., because of the cost of the condensers. A special grounded guard is placed about the primary inductor to prevent shock, and a "focus inductor" may be used, consisting of a device placed inside the primary inductor and consisting of two parts joined together, one part near the primary, made of copper, and the other near the crucible and in contact with it, made in a

¹⁵Northrup, E. F., Production of high temperature and its measurement, *Met. and Chem. Eng.*, vol. 17, 1917, p. 685; Some results obtained in electric heating with high-frequency induction, *Pyrotechnic Monthly Bull.* No. 9, November, 1919. Anon., Northrup-Alot (General) Induction Furnaces, *Chem. and Met. Eng.*, vol. 19, 1918, p. 155. Anon., Electrical production of carbon-free alloys, *Chem. and Met. Eng.*, vol. 21, 1919, p. 258. see also Northrup, E. F., U. S. Patents 1,286,394; 1,286,395, Dec. 3, 1918; 1,297,393, Mar. 18, 1919; 1,328,336, Jan. 20, 1920; 1,336,133, Feb. 10, 1920; Wilcox, D., The 244-Northrup electric furnace, *Metal Ind.*, vol. 18, 1920, p. 213; Alloying precious metals electrically, *Metal Ind.*, vol. 19, 1921, p. 171.

¹⁸Northrup, E. F., Principles of inductive heating with high-frequency current, *Trans. Am. Electrochem. Soc.*, vol. 35, 1919, p. 71; (abstract) *Met. and Chem. Eng.*, vol. 20, 1919, p. 391. High frequency induction steel furnace, *Chem. and Met. Eng.*, vol. 24, 1921, p. 100. Bessemer process in high frequency inductive heating, *Trans. Am. Electrochem. Soc.*, vol. 38, 1921, p. 159. see also Chamer, G. H., The induction electrical furnace, *Jour. Franklin Institute*, vol. 160, 1920, p. 471; Krietzberg, E. C., Melts metal for pipe in the solid (Chamber process), *Foundry*, vol. 49, 1921, p. 777.

brass melting furnace, of nichrome or Monel metal. This focus inductor may be grounded so that the high tension primary is within two grounded guards. The focus inductor also tends to increase the "close coupling" of the primary and secondary circuits, though it has the disadvantage of introducing something beside the material to be melted and the crucible containing it in the hot zone, which is against reliability, and limits the temperatures obtainable to the safe operating temperature of the material used for the inner portion of the focus inductor.

Condensers are fairly reliable and long lived; if properly housed outside the furnace room, they need not give much trouble. In order to avoid deterioration of the condensers by overheating, it is necessary, if the furnace is to be operated 24 hours a day, to provide two sets of condensers so that one may be cooling off while the other is in use, for artificially cooled condensers have not been constructed.

The power factor of a Northrup furnace on a Tesla circuit runs from 50 to 60 or 75 per cent.

The gap requires attention about every 500 hours to keep it in working order, and about 1 pint of denatured alcohol is used every 300 kw. h. For small installations, such as in the physics departments of universities or for some commercial work in the melting of small amounts of precious metals, the Tesla circuit is satisfactory.

The high-frequency current may also be obtained from an oscillatory current high-frequency generator, which has been built up to a 60-kw. size, or from a high-frequency alternator, which is already commercially built in 200-kw. or larger sizes, and would probably be the best commercial source. With the high-frequency alternator, by suitable use of static capacity, the power factor of the circuit can be made unity.

As high-frequency current is not at present generated or transmitted by central stations, a foundry wishing to utilize the Northrup furnace must either be content with a comparatively low-powered furnace and with the use of a condenser set or else install its own high-frequency alternator. The high voltage used at usual low frequencies would be dangerous to life, and great care is taken to construct the furnace so that it is grounded to avoid shock. It is probable, however, that at the high frequency employed these high voltages are not dangerous, as in a test made by the Ajax Electrothermic Corp. a rabbit withstood the full voltage without injury.

The Ajax-Northrup furnace is therefore, so far, useful for research in physics and metallurgy, especially as the furnace can readily be constructed as a vacuum or a high-pressure type and for an at present limited field of commercial uses. Over 30 Ajax-Northrup furnaces have been installed for laboratory use. The furnace can

not at present be classed as ready for general commercial use for brass melting under existing conditions. The ultimate possibilities of this type of furnace are great, but much development must be made on the production of high-frequency current before the possibilities in brass melting can be realized. The furnace itself is probably much closer to commercial usefulness than the generation of the current it requires, and it is now of commercial value for handling the more precious metals.

Small furnaces for commercial metal melting have been sold to Baker & Co. for melting platinum, to J. R. Wood & Co. for melting gold, four to the Philadelphia Mint for melting gold and silver (see Pl. XXV, p. 265), and a nose-tilting, three-phase, 60-kw., 550-pound furnace was put into operation, melting silver, at the plant of Handy & Harmon, in June, 1920 (see Pl. XXII, B, p. 262). By the use of a three-phase system it was possible to secure a decidedly larger capacity in a given condenser than before. The power factor is around 70 and the furnace melts sterling silver at about 250 kw. h. per ton.

The Director of the Mint¹⁹ speaks very highly of the Ajax-Northrup furnaces used at the mint for melting silver.

A recent form of the Ajax-Northrup, called an "electric crucible," consists of a conical hearth. This, for melting brass or other materials of high electrical conductivity which are not contaminated by carbon, is lined with graphite. Melting can be done by the current induced in such metals, but not so rapidly nor so efficiently as when a conducting lining is used. Materials of high resistance, such as iron and nickel, do not require the conducting lining.

The conical pot with its surrounding coil is mounted in a box-like container which may be lifted off bodily just like a crucible, and poured with a special shank, or it may be tilted for direct pouring. A 150-pound 25-kw. furnace of this type is being tried out at the Ajax Metal Co.

That the eddy current furnace itself is efficient is shown by a test of an 18-kw. furnace which melted copper at the rate of about 240 kw. h. per ton, using power from an Alexanderson alternator. With oscillatory current from a condenser set, the power consumption was at the rate of about 500 kw. h. per ton when the power losses in the transformers, condensers, leads, etc., were included.

The furnace gives a circulation of the charge, the metal flowing upward in the middle of the crucible and downward at the sides on account of electromagnetic forces.

The furnace therefore is like the Ajax-Wyatt in that the heat is at least partly generated in the metal itself, and in that a forced

¹⁹Paton, R. T., Report of the Director of the Mint for the fiscal year ended June 30, 1920, Trans. Dept., Dec. No. 2874, 1920, p. 19.

circulation is set up. It has no secondary loop in which a freeze-up will ruin the lining, and all the metal can be poured or tapped from the furnace when made in the noncrucible type. It is therefore free from the limitations of the Ajax-Wyatt as to changing from one alloy to another, and it can handle pure copper as well as alloys high in zinc. It does not have to be kept hot over night. It is almost as efficient on a first heat as it would be after a week of 24-hour operation per day, because the thin heat insulation used in order to get "close coupling" is so small that there is very little heat storage in the walls. The use of thin walls may, of course, reduce its mechanical stability. However, the freedom from complications in the hot zones, no electrodes, no resistor, no secondary loop, makes it promise to have sufficient mechanical reliability. The condensers supplied with the Tesla outfit are guaranteed for one year. The price of the 60-kw. furnace, Tesla circuit outfit, for 220-volt, 60-cycle power, was given in June, 1920, as \$6,750 for the crucible lift-out and as \$7,000 for the trunnion tilting form. That of a 25-kw. furnace of the portable "electric crucible" type, holding 10 pounds of aluminum or 30 pounds of copper, was given as \$3,350 in 1921.

The combination of efficiency and flexibility makes the furnace perhaps the most promising of all for ultimate use, provided it can be satisfactorily developed into larger sizes and high-frequency current can be almost as readily and cheaply obtained as ordinary alternating current is now. As high-frequency current can not well be applied to the ordinary uses of electricity, the furnace, while an excellent application of scientific ingenuity, does not seem likely to displace the common alternating-current furnaces in the immediate future. Its present field is in the laboratory, as a tool for experimental work, and in the commercial melting of precious metals such as gold, silver, and platinum.

ELECTRIC MELTING OF ALUMINUM.

The foregoing description of the various electric furnaces has dealt mainly with brass. One more very important class of nonferrous alloys, the light aluminum alloys, should also be considered in connection with electric melting.

Detailed information on electric melting of aluminum is about as unavailable as that on electric brass melting was a few years ago, and it is necessary to consider this subject more as theory than from present practice.

According to data recently gathered by the Bureau of Mines,²⁰ about 45,000 tons of light aluminum alloys are produced in the United

²⁰ Anderson, R. J., Light aluminum alloy castings: Tech. Paper 287, Bureau of Mines, 1922, 50 pp., 4 pls.; Analyze loss in aluminum shops: Foundry, vol. 48, 1920, p. 989, vol. 49, 1921, pp. 16, 54, 104, 143, 188.

States every year, around 98 per cent being aluminum-copper alloys and only 1½ per cent, or 750 tons, being aluminum-zinc or aluminum-copper-zinc alloys.

A single electric furnace of around 1-ton capacity could melt all the zinc-containing aluminum alloys produced in the country and not have to work much over 10 hours a day to do it. As it is only the zinc-containing aluminum alloys in which there is any noteworthy loss from volatilization, it is plain that the situation in regard to aluminum is diametrically opposed to that in brass. Oxidation losses do occur, and good metal is entangled in and skimmed off with the dross, but the net loss of metal in melting the standard No. 12 alloy is probably as low as 1 or 2 per cent. Moreover, those who have had the most experience in the electric melting of aluminum doubt whether, starting with the same charge, an electric furnace will save enough metal, more than a well-operated fuel-fired furnace, to make much difference in the cost.

Most aluminum is melted either in iron pots or in some type of reverberatory furnace. Where it is still melted in graphite crucibles, the crucibles have a relatively long life, hence two of the outstanding advantages of electric brass melting—reduction of metal losses and avoidance of high crucible costs—do not obtain in any marked degree in electric aluminum melting. On aluminum, therefore, electric melting must justify itself by quality, ease of control, decreased labor cost, or lower cost of electric power than of fuel required.

As to quality, everyone who has tried electric melting seems to agree that electrically melted aluminum is of good quality, and some seem to feel that it is or may be of superior quality. Perhaps because of the good general reputation of the electric furnace on the score of quality in handling other alloys, some aluminum founders are hoping that the electric furnace may do away with cracks, draws, and porous castings, or may at least eliminate the possibility of these troubles originating in the melting of the metal, thus leaving "only" the thousand and one molding and core causes that may produce these evils.

Work of a scientific character on testing the product for porosity²¹ indicates that the electric furnace offers possibilities, but even these tests were often discordant and contradictory. It can be said with considerable confidence that a reducing atmosphere is better for finishing steel and melting brass than an oxidizing atmosphere. But in view of the oxidizing atmosphere over an iron-pot furnace for aluminum and the fact that such furnaces can produce good metal, and that in a reverberatory type, oil-fired aluminum furnace the atmosphere may be made reducing, and that this type can also

²¹ Compare Deutscher, F. K., and Wilkins, R. A., Apparatus used for the determination of the porosity of metals. *Chem. and Met. Eng.*, vol. 22, 1920, p. 1031.

produce good metal as well as bad, one is not justified on present data in jumping to a conclusion that an electric furnace need be good for aluminum because it may have a reducing atmosphere. Overheating in an electric furnace seems to favor the absorption of gases and the production of castings containing tiny pinholes in exactly the same manner as it does in fuel-fired furnaces.

Neither on the score of theory nor recorded foundry tests of electric aluminum furnaces can we then assume any definite direct advantage for the electric furnace, save perhaps in the elimination of hard spots in the castings due to iron scale from the iron pot, an advantage shared by fuel-fired hearth-type furnaces as well.

In ease of control, there is a real advantage, because of the great effect that the rate of solidification, which is chiefly controlled by the pouring temperature, has on aluminum. Though it has never been satisfactorily explained, and hardly fully proved, there is a general idea that aluminum once overheated, and it may be in either a reducing or oxidizing atmosphere, is thereby irreparably injured, even though it be poured at the proper temperature. If this be so, then an electric furnace of a type not too sluggish in its response to changes of power input might be an advantage, and its use at any rate should make careful pyrometric control of pouring temperatures easier.

FURNACES USED BY GENERAL ELECTRIC CO.

The General Electric Co. uses a small 75-kw. furnace like their older type of electric brass furnace, holding some 75 or 100 pounds of aluminum to melt a nearly pure aluminum which must flow very freely as it must run down through the slots in a motor rotor. This rotor casting is made in an ingenious centrifugal casting machine, and to secure the desired results the temperature and fluidity of the metal and the speed of the centrifugal device must each be just right. The control over the metal made possible by the furnace, and the fact that the furnace itself is automatically operated, is considered to make the obtaining of good results more certain and easy than with a fuel-fired furnace. This furnace has been in use over a year and a half without relining, the only difficulty being that an accretion of oxide in the hearth has cut down the hearth capacity. On account of the low pouring temperature of aluminum compared to brass or bronze, almost any type of electric brass furnace applied to aluminum should have very little difficulty in maintaining the refractories.

The General Electric Co. also uses a larger furnace of the same type of about 800 pounds capacity, 150 kw., for ordinary aluminum casting work. It has also designed a very large furnace holding several tons, which it hopes to try out experimentally. The design calls for a long, rather narrow hearth with a weir or a dividing wall with a hole in it, about halfway up, between the two parts of the hearth.

Metal is to be charged at the back, melted, and clean metal, free from dross floating on top, or from foreign particles heavier than the metal, is to run through into the fore part. The rate of melting in the rear part of the hearth and of superheating to pouring temperature in the fore part can be regulated by adjusting the position of the electrodes along the front or rear to generate more or less power as desired. This scheme offers some possibilities, but they must be tried out before their value is certain.

The General Electric Co. is building still another type of electric aluminum furnace to be tried out at the Pittsfield, Mass., plant. This is a rectangular tilting furnace, like a long box, the hearth occupying the lower part, the heating element being strips of nickel-chromium resistance ribbon, such as is used in the heat-treating furnaces for gun forgings.²² The heating element is placed not only on the roof proper but also on the sides above the hearth. Such a resistor will not stand operation at temperatures sufficient to melt brass, but it may handle aluminum at a repair cost that will not be prohibitive. One factor leading the General Electric Co. to build this type was a desire to secure comparative data on the effect of the oxidizing atmosphere this furnace will have against that of the reducing atmosphere in the arc-resistance type used both for brass and aluminum.

The General Electric arc-resistance furnaces for use on aluminum are the same as for brass, save that the transformer capacity and power input are lower for the same size shell than on brass. They give the following table for different sizes on basis of 24-hour operation, after furnace is fully hot:

TABLE 53.—*Maker's claims for General Electric aluminum furnace.*

Kw.	Hearth capacity, pounds.	Nominal pounds melted per hour.	Approximate kw. h. per ton.
200	650	500	525
300	1,000	750	500

One Baily standard 105-kw. furnace is regularly operating on No. 12 aluminum at the plant of the Dayton Engineering Laboratories Co., Dayton, Ohio. A test run on the furnace showed an output of about 1½ tons per day, in 8½ actual hours melting, plus 1 hour pre-heating the furnace, or 7 to 8 heats of 425 pounds each. The average power consumption ran from 625 to 675 kw. h. per ton. The Delco people state that they are very well satisfied with the furnace.

²² Johnson, L. F., How the powerhouse aids the forge, *Iron Trade Review*, 1919, p. 1223, Johnson, L. F., Metallic resistor electric furnaces for heat-treating operations, *General Electric Rev.*, vol. 23, 1929, p. 433.

At the plant of Landers, Frary & Clark, New Britain, Conn., one of the 50-kw. rectangular Baily furnaces was operated for about two months before it was taken out on account of trouble in maintaining the resistor trough, to be later replaced by the round type. This furnace, melting 9 hours per day and being preheated 4 hours, gave on 150-pound heats an output of $\frac{1}{2}$ ton per day, at 850 kw. h. per ton. The net metal loss was about 0.7 per cent.

One of the 105-kw. Baily furnaces was tried out some years ago by the Aluminum Co. of America for making ingot from pig aluminum, but was not kept in service, being considered too small for such work, and not showing any particular advantage as to metal losses.

A big 500-kw. tapping-type Baily furnace was later installed at the plant of the United States Aluminum Co., at Massena, N. Y. This type has been described by Miller.²³

It has two straight resistors, one on each side of the hearth, and held 3 to 4 tons of aluminum. In this furnace, according to the users,²⁴ under best conditions and continuous operation, the production was about 1 ton per hour at slightly under 500 kw. h. per ton. The furnace was primarily installed for making alloys high in zinc, and on such service it showed a notable decrease in metal loss over the fuel-fired reverberatory furnaces. But on the regular run of aluminum there was no decrease in metal loss. The resistor troughs have been a source of trouble, failing frequently, and the high heat capacity of the furnace makes it less efficient on intermittent operation, the power consumption averaging some 700 kw. h. per ton on the furnace as actually operated over a period of time.

As a consequence of the high power consumption the use of the furnace has been practically given up, and its owners contemplate changing it over into an annealing furnace, as such furnaces give very satisfactory results at the lower operating temperatures used in annealing.

It should be mentioned that a 105-kw. Baily furnace has long been in satisfactory operation at the Lumen Bearing Co., Buffalo, N. Y., on an alloy of around 85 per cent zinc, 10 per cent copper, 5 per cent aluminum, which is poured at about 700° C. The furnace gives around 5,500 pounds per 10-hour melting day, using about 660 kw. h. in the daytime and 330 at night to keep the furnace hot, or about 360 kw. h. per ton on this low-melting alloy. The use of the large 1,000-kw. Baily furnace installed at the Anaconda Copper Mining Co. has been discontinued.

A few isolated heats of aluminum have been made in Snyder direct-arc furnaces, but no data of consequence are available. If

²³ Miller, D. D., The remelting of aluminum pig in the electric furnace, *Chem. and Met. Eng.*, vol. 19, 1918, p. 251.

²⁴ Vail, A. E., Personal communication, Jan. 21, 1920.

the direct-arc furnace will produce a satisfactory quality of metal, without undue gas absorption in the overheated metal under the arc, such a furnace should work well. The common aluminum alloys, outside of the zinc-containing alloys, are relatively non-volatile, and in general, direct-arc furnaces are useful for such alloys. This question ought to be investigated, and the Bureau of Mines hopes to study it.

The Rennerfelt indirect-arc furnace in a small 50-kw. size was used by the Acieral Co. of America in making up "hardeners," but not in melting the aluminum alloy itself, before that firm went out of business. Similar hardeners are now handled in this furnace, using 100-kw. transformer capacity, at the Bausch Machine Tool Co., Springfield, Mass. No real tests of stationary indirect-arc furnaces on aluminum alloys themselves are on record. On the basis of some small test runs in the 50-kilowatt furnace, made by starting with the furnace at the temperature used for making hardeners, and therefore well above aluminum temperatures, it was calculated that in a 1-ton furnace 310 kw. h. would be required, presumably on 24-hour operation. These figures were later revised to 350, but neither figure is based on adequate test.

One of the standard Detroit rocking furnaces rated at 300 kw. was given a thinner lining than for use on brass, the melting chamber being 49 inches in diameter by 41 inches, the furnace thus lined holding 1,700 pounds of aluminum, and was tested at the C. B. Bohn Foundry Co., Detroit. The power input was raised to 325 to 375 kw., and on about 60 tons of No. 12, the actual melting time averaged about 1 hour, 10 minutes per heat, corresponding to an output of about 5 tons per 10-hour day, at about 475 kw. h. per ton. The net metal loss averaged about 0.85 per cent, running about 0.4 per cent on American ingot, scrap No. 12 and gates, and up to 1.3 per cent on some French ingot that appeared to contain some nonmetallic impurities that were weighed in as metal. It is also possible that there was some formation of aluminum carbide due to piling the charge too close to the arc in the runs on the French metal which were made first. The product from both the French and American metals was of satisfactory quality. A 1,200-pound Detroit furnace is operating on aluminum at the Storm Peak Potash Co., Denver.

The Ajax-Wyatt induction furnace has not been tried on aluminum.

It will be noted that all the data on aluminum show a high power consumption per ton of metal compared to that required by the same furnace on brass. The figures range on 10-hour operation from 850 kw. h. per ton in the 50 kw. Bailly on 150-pound heats, through 650 kw. h. per ton in the 105-kw. Bailly on 425-pound heats, to 475 kw. h. per ton in the 375 kw. Detroit on 1,700-pound heats, and the 24-hour operation figures for the 3 to 4 ton Bailly tapping furnace,

and for the 1,000 to 1,400 pound General Electric furnaces, are 500 kw. h. per ton under the best conditions. Roughly, a given size and type of furnace requires at least 50 per cent more power per ton to heat aluminum to 700° C. than it does yellow brass to 1,050° C.

In fact, theory calls for the expenditure of about twice as much energy as, averaging the available data, 100 per cent melting efficiency calls for about 150 kw. h. per ton for yellow brass²⁵ and 300 kw. h. per ton for No. 12 aluminum.²⁶

In fuel-fired furnaces the difference in fuel consumption is not so marked because such furnaces operate at a higher efficiency the lower the temperature, so that a given fuel-fired furnace can probably produce a ton of aluminum with not much more fuel than it would use on yellow brass.

As there are no such savings in metal losses and in crucibles as in brass melting, and there is no definite proof of improved quality of metal, the value of electric furnaces for aluminum depends on whether or not an aluminum melter can melt cheaper by paying perhaps \$7 to \$10 or more per ton—depending on the cost of power and the size and type of electric furnace chosen—for electric power plus the interest and depreciation charges per ton on an expensive furnace (that will give only a small output, compared to brass, of aluminum) than by paying his present fuel costs. At 1920 fuel prices he might often do so, but he seldom has the incentive of so great a saving as to make a change imperative. On the other hand, the larger aluminum founders may often have so large an output that the large amount of electric power they would use for melting would come at a low figure and make a respectable saving. Similarly, plants melting brass electrically could add electric furnaces for their aluminum and could often get the added amount of power required at a rather low figure. Convenience, coolness, and cleanliness of the electric furnace might also be deciding factors.

But any use of electric furnaces for aluminum comparable to that for brass will be a slower development, unless it is definitely proved that some electric furnace operated in some particular manner will really improve the quality of the metal and will materially cut down the percentage of defective castings. There is a good chance that this may be possible, but it has not yet been demonstrated. Another

²⁵ Compare Richards, J. W., Electric power required to melt metals. *Trans. Am. Brass Founders' Assn.*, vol. 4, 1910, p. 95. Clamer, G. H., and Hering, C., The electric furnace for brass melting, *Trans. Am. Inst. Metals*, vol. 6, 1912, p. 101. Hansen, C. A., Electric melting of copper and brass, *Trans. Am. Inst. Metals*, vol. 6, 1912, p. 112. Also unpublished data from Bridgeport Brass Co.

²⁶ Compare Laschtschenko, P. N., Specific heat of aluminum: *Jour. Russ. Phys. Chem. Soc.*, vol. 10, No. 56, 1914, p. 311; Merica, P. D., Aluminum and its light alloys: U. S. Bureau of Standards, Circular 76, 1919, p. 27; Wüst, F., Meuthen, A., and Durrer, R., Thermal constants of technical materials: *Zelt. Instrumentenkunde*, vol. 39, 1919, p. 294; *Chem. Abstr.*, vol. 14, 1920, p. 1241.

possible use for electric melting furnaces which has yet to be thoroughly demonstrated is in melting cathode copper.

DIRECT-ARC AND OTHER FURNACES FOR MELTING CATHODE COPPER.

Lyon and Keeney²⁷ point out that the purity and conductivity of cathode copper are reduced by the impurities introduced in reverberatory melting and that it is possible to melt it in the electric furnace without the absorption of impurities.²⁸ The possible application of the various types of furnace available in 1914 is considered. The horizontal ring induction furnace is barred out because of troubles from pinch effect due to the high conductivity of the material; the pinch-effect furnace is similarly barred because of the low voltage required; the stationary indirect-arc furnace is considered a possibility but on account of the cost of upkeep is not thought to be as promising as a direct-arc type with a nonconducting bottom, such as the Heroult.

Possible loss of copper by volatilization, according to Lyon and Keeney, can be prevented by the use of a slag. In experimentally testing the operation of a direct-arc furnace on copper, however, it should be recalled that there have been severe and almost fatal cases of copper poisoning from melting copper under a direct arc. Suitable ventilation should be provided, and masks or respirators supplied, at least until it has been shown that, under the conditions under which the furnace will be operated, there is no possible danger from poisoning. The power consumption is calculated to be about 300 kw. h. per ton in a 25-ton direct-arc furnace. No commercial application of the electric furnace to the melting of cathode copper appears to have been made. The superintendent of a large copper rolling mill said in 1917 that the remelting of cathode copper, even without loss of conductivity, must be done at a cost of not over \$1.50 per ton; so that power would have to be considerably cheaper than one-half cent per kw. h. to make electric melting possible.

Bally says²⁹ that cathode copper can be melted electrically without blowing or poling and with only the sulphur from the copper-sulphate electrolyte contained in the cathode as charged and cites two heats in a Bally 105-kw. furnace. The cathodes were sheared to separate the edges, which occlude more electrolyte, from the centers.

²⁷ Lyon, D. A., and Keeney, R. M., Melting cathode copper in the electric furnace: *Am. Inst. Min. Eng. Bull.* 92, August, 1914, p. 1791.

²⁸ Lyon, D. A., and Keeney, R. M., Smelting copper ores in the electric furnace: *Am. Inst. Min. Eng. Bull.* 80, August, 1913, p. 2117.

²⁹ Bally, T. F., Resistance-type furnaces for melting nonferrous metals: *Chem. and Met. Eng.*, vol. 21, 1919, p. 11; *Trans. Am. Electrochem. Soc.*, vol. 35, 1919, p. 411.

Quality of copper melted in a Baily furnace.

	Charge.	Analysis.			Conductivity.
		Cu.	O.	S.	
Heat A.....	Cathode edges.....	99.904	0.084	0.0021	<i>Per cent.</i> 100.1
Heat B.....	Cathode centers.....	99.950	0.036	0.0012	100.8

Baily says that the large resistor type of furnace tried for zinc cathodes will be used for melting cathode copper. The contrary opinion has already been cited of a copper rolling mill which has used a 105-kw. Baily furnace for brass, but does not consider the resistance type worthy of consideration for large-scale copper melting. Some interest, however, has been shown by the larger melters of cathode copper in the possible adaptation of General Electric and Foley furnaces for this purpose.

The General Electric furnace has been operated at the United States Copper Products Co. on new copper with some heavy tube scrap. The quality of the product is said to be satisfactory when no metallic impurities are present and the copper is poled prior to phosphorizing. The furnace is said to be much less satisfactory for pouring a pure, tough pitch, unphosphorized copper.

A Detroit rocking indirect-arc furnace has been used for melting cabbaged copper wire and scrap copper into wire bar, and its users state that metal of 100 per cent conductivity, Mathiesen scale, is produced without the use of fluxes or deoxidizers. The charge must, of course, be free from metallic impurities. The Bennett contact-resistance furnace is also said to be satisfactorily employed in melting pure copper.

The electric furnace has a big advantage over crucibles for melting brass in that it can readily produce equal quality in larger melting units, but it is at a corresponding disadvantage in melting cathode copper in that no electric melting furnace has yet been built with a capacity of over 40 tons of molten steel, and few, if any, with over 10 to 15 tons capacity have been built to melt cold stock, whereas reverberatory copper furnaces often take 200 tons and upward per charge.

Moreover, it is stated ³⁰ that recent advances in reverberatory practice have allowed the use of high-sulphur oil for reverberatory melting of cathodes without trouble from sulphur in the wire bars.

The upkeep of the refractories in a direct or indirect arc furnace, the only types likely to prove efficient enough in the use of power

³⁰ Hydrometallurgy and pyrometallurgy of copper in 1919. Chem. and Met. Eng., vol. 22, 1920, p. 7.

unless induction furnaces are developed enough to be applicable, is almost certain to be more difficult than in a fuel-fired reverberatory, and until this factor can be overcome the large-scale electric melting of cathode copper does not seem likely in the near future.

CHOICE OF A FURNACE.

In choosing an electric furnace for a given plant, or in selecting two furnaces for comparative test, the first thing to consider is the alloys to be melted, so that the furnace chosen may be metallurgically fit for the work in hand and for the range of alloys. For nickel chromium and Monel metal one can use the Heroult, Snyder, Greaves-Etchell, or the Rennerfelt, and possibly the rocking type or the General Electric. The two latter would be at a disadvantage because the refractories ordinarily used in them are not meant for use at such high temperatures. The possible application of the direct-arc type to pure copper depends on the true answer to the yet unsolved question as to whether there will be poisoning of the workmen by volatilized copper. The General Electric furnace, though used on copper, begins to have considerable trouble in maintaining the roof on account of the high temperature. On gun metal one can probably use any of the furnaces. On "85-5-5-5," the point in zinc content at which a direct-arc furnace will not cause too great loss of zinc, has probably been passed.

On 74 copper, 4 tin, 5 lead, 17 zinc one could use any type save the direct-arc, but the Rennerfelt begins to have trouble through volatilization of zinc, and the lead content is near the upper limit for safety of the present lining of the Ajax.

Another point demanding consideration on alloys high in lead or on yellow brass is whether a thorough mixture of the alloy is essential. If it is, the rocking type on the high lead alloys and the Ajax and rocking furnaces on yellow are indicated, as against the types that require hand stirring to insure thorough mixing.

When the furnaces that are entirely fit metallurgically are chosen for a given alloy, the metal losses should be low, and practically equal in all the fit types, so that the choice of an individual furnace rests on other factors than the metal loss, though that may often be the determining factor in choosing electric furnaces as a class to replace fuel-fired furnaces.

The range of alloys to be melted in the same furnace must be considered. For example, a firm making both ordinary red brass and yellow brass could melt the former in a Rennerfelt and the latter in an Ajax, and if it had sufficient production to keep the Rennerfelt always working on red and the Ajax always on yellow, it would have a good combination in the use of both furnaces. But if the same

furnace must be able to melt a heat of red, followed by one of yellow, neither furnace will do, and the choice must be made from the furnaces that will handle both alloys. The metallurgical fitness of the various furnaces is shown in Table 54.

When the possible furnaces have been separated from those that are unfit on the basis of metallurgical ability and versatility, the choice can still be narrowed down further by considering the furnaces as to their fitness on other lines. A rolling mill or a smelting and refining plant that can operate 24 hours a day and can use almost any amount of metal any time it is ready to pour has a different problem from that of a small jobbing shop that plans to run but one shift per day and perhaps requires heats of various alloys and in various amounts and can not dispose of a very large heat at one time. The next thing to consider, therefore, is the daily production desired and the size of the heats needed. A further sorting of the furnaces may be made to select a type and a size of a given type suitable for the work. A rolling mill may desire to pour direct from furnace to mold and hence chooses a furnace from which such pouring can be done, and selects one taking a charge that will just fill a certain number of molds. The tendency there might be toward not too large sizes and toward the more compact furnaces, as pouring direct from these is more easily controlled. Another rolling mill may wish to break away from small charges or small ingots to see if economies can not be introduced by large scale units, so that they choose the furnace taking the largest charge from among the otherwise suitable ones.

TABLE 54.—*Applicability of various types of electric furnace to various alloys.*

Alloys.									Types of furnaces.						
Fe.	Cr.	Ni.	Cu.	Sn.	Pb.	Zn.	Ag.	Al.	Direct arc.	Stationary indirect arc.	Moving indirect arc.	Reflected heat.	Contact resistance (Bennett).	Vertical ring induction.	High frequency.
	15	85	.....	.....	.....	.....	.....	.....	O. K.	O. K.	O. K.?	? 1	?	?	O. K.?
5	.....	67	28	.....	.....	.....	.....	.....	O. K.	O. K.	O. K.	? 1	?	?	O. K.?
		25 5	75 95	.....	.....	.....	.....	.....	? 2	O. K.	O. K.	O. K.	O. K.?	?	O. K.?
			100	.....	.....	.....	.....	.....	? 2	O. K.	O. K.	O. K.	O. K.	No 3	O. K.
			90 88	10 10	 2	.....	.....	.....	O. K.	O. K.	O. K.	O. K.	O. K.?	? 3	O. K.
			80 76 68	10 3 4	10 18 26	 3 2	.....	.....	O. K. 5	O. K.	O. K.	O. K.	O. K.?	No 4	O. K.
			85	5	5	5	.....	.....	No 5	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.

TABLE 54.—Applicability of various types of electric furnace to various alloys—Continued.

Alloys.									Types of furnaces.						
Fe.	Cr.	Ni.	Cu.	Sn.	Pb.	Zn.	Ag.	Al.	Direct arc.	Stationary indirect arc.	Moving indirect arc.	Re-flected heat.	Contact resistance (Bennett).	Vertical ring induction.	High frequency.
			71	4	5	17									
			80			20									
			70			30									
			67		3	30			No-5	No-5	O. K.	O. K.	O. K.	O. K.	O. K.
			61	1		38									
			65		1	34									
			60			40									
		18	58			24			No-5	No-5	O. K.	O. K.	?	O. K.	O. K.
			3			15		82	No-5	? 5	O. K.	O. K.	?	? 3	O. K.
			2			30		68			O. K.	O. K.	?	? 3	O. K.
			8					92	?	O. K.?	O. K.	O. K.	?	? 3	O. K.
			10					90	?	O. K.	O. K.?	O. K.?	?	? 3	O. K.
			10			85		5	No	No-5	O. K.?	O. K.	?	?	O. K.?

- O. K. = Furnace metallurgically satisfactory for this alloy.

? = No data on hand.

O. K. = Probably satisfactory, but no record of trial.

No = Furnace not satisfactory for this alloy.

1 = Temperatures probably rather high for good refractory life.
- 2 = Question of copper poisoning by fume from direct arc not yet settled.

3 = Induction furnace on this alloy would require resistor tube of special design.

4 = Lead too high for good life of usual lining of induction furnace.

5 = Furnace causes loss of volatile metal from this alloy.

A firm that can dispose of metal rapidly desires to use the furnace that will give the greatest production in the one, two, or three shifts they plan to work, and the high rate of production may be most important in relation to labor per ton of melt, to floor space, or to the original investment in the furnace.

ELECTRIC POWER AVAILABLE.

If electric power is cheap, convenience, low labor cost, or the avoidance of electrode cost, may indicate a choice of a furnace relatively inefficient in use of power. If power is dear, the more efficient the furnace is in the use of power the more likely it is to be preferred. If a plant is to take power from a small central station, the size and nature of the furnace load must be such that the central station will accept the load. Furnaces otherwise better fitted for the plant's need may therefore have to be passed over in favor of a furnace with electrical characteristics suitable for the location. Again, between two suitable furnaces, a choice may be made on the basis of upkeep cost, life and cost of lining, electrode consumption and breakage. It may be cheaper to use a very high-powered furnace and to replace refractories often in order to get a high rate of production, or it may be cheaper to use a low-powered, inefficient furnace with a low rate of production to avoid refractory troubles; more likely, it is better to choose one that falls between the two extremes.

SPECIAL CONDITIONS.

Finally, after the most suitable electric furnaces have been selected, a comparison should be made for special conditions: The alloys melted, the number of shifts worked, the power and fuel costs, the labor costs, the upkeep costs, the metal losses, and their value, and the health and safety conditions of fuel-fired furnaces already in operation or chosen from the various available types and sizes of fuel-fired furnaces in a fashion similar to that employed in selecting the type and size of electric furnace.

In this comparison, the first cost of the electric furnace must not be forgotten, though it is often neglected in the comparisons of melting costs put out by electric furnace makers. One can either include an interest and depreciation charge per ton based on the sum of these items per year, divided by the yearly output, or he can omit it, and then figure, from his calculation of the savings shown by electric melting over fuel-fired furnace melting, how long it will take, at the rate of production of the particular electric furnaces considered, to pay for each of them and how much they will thereafter save him.

On account of the initial cost and the interest charge one should not install so many electric furnaces that some will stand idle most of the time, being there simply to handle small peaks of production in excess of the normal; for excess production a plant should utilize fuel-fired furnaces of lower initial cost.

It is impossible to draw up any accurate blanket comparison of melting costs in fuel-fired furnaces and electric furnaces. Melting cost in fuel-fired furnaces varies with a multitude of conditions, and so does melting cost in electric furnaces. When the varying conditions are known, a dollar-and-cents comparison is the most striking and convincing method possible.

But such figures are of little real value unless they are calculated for a particular rather than for a general case, and to give general figures in this report is deemed inadvisable.³¹ The cost figures given in the advertising literature of some furnace makers, therefore, will not be quoted. Instead, in the discussion of the performance of the various furnaces, such data as could be collected have been given as would allow an individual plant to make the calculation of melting costs for its own conditions.

When electric brass melting is a little older, valuable comparisons can be made of the performance of two or more types and sizes of electric furnaces in the same plant, as then the conditions of operation of both types can be made similar. A number of firms have two or more types of electric brass furnaces, and one firm has tried

³¹ Compare Electric furnace progress, *Metal Ind.* vol. 17, 1919, p. 230.

five makes of electric furnaces, but it is unusual that more than one type has been installed long enough so that accurate data are available on the different types or else the different types have not been tested on the same classes of work. Valuable, accurate, comparative data on performance should become increasingly available from these plants in the future.

After a proper type and size of electric brass furnace has been chosen to meet the specific conditions of a particular plant, the furnace should be installed and operated to the best advantage.

INSTALLATION OF AN ELECTRIC FURNACE.

There are certain points in the installation which require the attention of some one with a knowledge of electrical engineering, as applied to electric furnaces, rather greater than that possessed by the ordinary firm of electrical contractors, so that the advice of either the furnace maker or the central station should always be taken rather than to depend entirely on a plant electrician or on a contractor. These points mostly center around the fact that carrying alternating currents of, say, 2,000 amperes is a different matter from that of carrying the much smaller currents of the ordinary power or lighting circuit.

Compared to the problems³² involved in carrying currents of 20,000 amperes often required by large ferro-alloy or iron-smelting furnaces, or even current of 5,000 to 10,000 amperes, as taken by large steel-smelting furnaces, the problems with the brass furnaces, even the largest, are fairly simple.

For example, in one of the Swedish iron-smelting furnaces, taking 3,600 kw., the losses between the transformers and the furnace were 475 kw. with one method of running the leads from transformers to furnace, while with another the losses were cut to 285 kw., the power factor being at the same time brought up from 70 to 90.

Beside the actual saving of energy, the change made 3,500 kv. a. of transformer capacity capable of sending more energy to the furnace than a capacity of 4,500 kv. a. sent before.

In another 4,000-kw. furnace, 490 kw. were lost between transformers and electrodes, 165 kw. in the leads themselves and 315 kw. in the structural ironwork near those leads. Power used in heating up

³² Compare Lindström, A., Leads for electric furnaces, *Met. and Chem. Eng.*, vol. 16, 1917, p. 443. Hultgren, F., Problems in electric furnace smelting, *Chem. and Met. Eng.*, vol. 22, 1920, p. 165. Anon., Low tension conductors for electric furnaces, *Elec. Rev.*, vol. 76, 1929, p. 187. Meyer, A. A., Electrical characteristics of electric furnaces, *Trans. Am. Electrochem. Soc.*, vol. 31, 1917, p. 27. Winterman, R. F., Electric steel castings, *Trans. Am. Electrochem. Soc.*, vol. 33, 1918, p. 293. Anon., Frequency for and capacity of electric furnaces, *Elec. Rev.*, vol. 75, 1919, p. 1069. Editorial, Transformers for electric furnaces, *Elec. World*, vol. 75, 1929, p. 880.

leads or nearby ironwork never gets into the furnace, but it has to be paid for just the same.

In a Heroult steel furnace of about 1,300 kw. it was found that the voltage drop in one of the leads passing near some structural steel was over three times the drop in another similar lead more remote from the steelwork. The leads were originally made up of bus bars held apart to allow ventilation and radiation of heat by copper spacers, which made the whole lead essentially one big conductor instead of several separate conductors in parallel. By merely taking out the copper spacers and inserting insulating spacers the voltage drop was decreased, and the furnace was enabled to do more work and to make its heats faster and at a lower power consumption.

All this peculiar behavior of leads carrying heavy currents is due to the fact that alternating current travels in waves, first in one direction and then in the other. The more often the waves travel, the greater the complications.

With direct current, such as we have in storage batteries, electroplating, etc., the current travels steadily in one direction. But direct current can not be transformed from one voltage to another and hence must be generated at the voltage at which it is to be used. It must, therefore, be transmitted at low voltages and high currents. Alternating current, on the other hand, can be generated at many thousands of volts and transmitted over long distances over tiny wires at very low currents. Since the heating of a conductor depends on the current and not the voltage, and increases as the square of the current, this high-voltage, low-current transmission at low currents means that there is a huge saving both from the diminution of energy losses and from the decreased cross section of conductor required.

When the high-voltage alternating current has been brought to the point where the power is used, it is merely run through a transformer that can change it to the lower voltage desired, at a correspondingly higher current. For this reason all electric furnaces that need merely heat, and not the electrolytic action of the direct current, use alternating currents.

With direct current the same number of amperes of current passed through the same cross section of a copper conductor gives the same heating effect no matter what the shape of the conductor or whether it is near other conductors or not.

Direct current will magnetize nearby iron or steel, but it does not cause in them the losses due to inductive or eddy current that are caused by alternating current. With alternating current, where the current changes in magnitude from zero through the maximum to zero again, as well as in direction, 60 times a second on 60-cycle current, and 25 times on 25-cycle, and the changes in the current bring in

the effect of "reactance" or an inductive effect. With direct current a conductor opposes the flow of current by resistance only, while with alternating current it opposes that resistance plus reactance as well, and reactance is affected by the size and shape of the conductor and by the proximity of other conductors and of iron or steel. If to a big electric furnace for making calcium carbide, for example, carelessly installed, were supplied, in order, three different sorts of current at the very same voltage, the furnace might take 5,000 kw. on direct current, 4,000 on 25-cycle, and 2,500 on 60-cycle alternating current. By proper subdivision and interlacing of the leads, and by avoidance of nearby iron, the last two figures might be brought up much nearer the first.

It is not necessary to go deeply here into the various effects of reactance, such as the power factor, skin effect in conductors, eddy currents, and other losses in near-by iron or steel here, but it is worth while, however, to point out that these factors exist, and that disregard of them may mean that the cost of the leads between transformers and furnaces may be much higher than is necessary, and that avoidable losses of energy, costing as much per unit as energy usefully employed in the furnace, may take place every day the furnace is used.

The foundryman must trust the furnace maker or the central station to specify the proper size and shape of the leads and to see that they are properly installed. He should be sure that the knowledge of and experience with heavy current conductors of whomever he chooses to trust is adequate.

Generally speaking, the shorter the secondary leads are from high-tension transformer to the furnace and the farther they are from girders and structural ironwork the better. The ideal arrangement is to have the high-tension switchers, meters, etc., in a properly inclosed room, kept locked against intrusion in order to prevent danger to life from high-voltage current, with remote control switches on the furnace switchboard for throwing off and on high-tension current.

A fatal accident occurred on a direct-arc furnace of rather higher voltage than the most modern form, on which the primary switch was not controlled from the furnace. A workman was putting the furnace into shape after relining it and stood so that his body made contact between upper and lower electrodes. A fellow workman evidently became confused as to which of two switches at some distance from the furnace was the one that controlled a circuit that he wished to close, and he closed the switch to the furnace, and the man working on the furnace was killed. Under working conditions there is usually no danger whatever in an electric brass furnace properly installed, but

even the low voltages may be dangerous, as even a low-voltage, high-current circuit closed through the body may bring serious results. The safe way is to open the high-tension circuit entirely when one wishes to turn the current off, and to do this from a control board at the furnace itself.

All the commercially used electric brass furnaces can be installed so as to be safe.

The transformers themselves should be placed outdoors wherever possible, or else in special transformer rooms or cells. If it can be avoided, high-tension current should not come into the foundry itself.

To get short secondary leads, the furnaces are placed preferably close to a wall, with the transformer directly back of the wall on the other side. The higher the current in the secondary leads the more important it is for them to be short.

Besides the losses of energy in the leads there are losses in the transformers and in the electrodes, but they depend on proper materials, design, and proportioning, for which makers of the transformers and the furnaces are responsible.

As soon as a furnace is installed a comparison should be made between the reading of the kw.-h. meter on the primary, back of the transformer and leads, and the reading of that on the furnace switchboard by which the furnace is operated, if this, as is usually the case, is connected up on the secondary side and shows the energy that gets to the electrodes, but does not include losses in transformer and leads. If such a comparison shows not much over 5 per cent loss between the power on the primary side, that paid for, and that on the secondary, the installation is pretty good. A loss of 10 per cent would not be unusual if the secondary leads are very long. Higher losses would indicate that the installation could probably be improved.

REFRACTORY LININGS.

The first refractory lining for a furnace is usually supplied by the furnace maker. After that is worn out the user may and usually does, sooner or later, try some other lining, and he may experiment with all sorts of refractories and with large bricks, or even one-piece liners, with small bricks, and with rammed-in linings.

On account of changes in prices of refractories and varying freight rates, different refractories may be called for in different localities or in the same locality at different times. Each type of furnace has its own peculiar requirements, and the nature of the charge, the amount and nature of slag-forming nonmetallic impurities, and the way the furnace is run all have a bearing on the refractory problem.

The ideal lining would never wear out, would allow no heat to escape through it, and would itself take up no heat. No lining is

ideal in any one of these points. Each factor is of about equal importance. Long life is desirable, and the less often the furnace is down for relining the lower the cost, not only of refractories and of labor for laying them, but also of the overhead on a nonproductive furnace. But long life may very possibly be attained at too great an expense for expensive electric heat lost through the lining, and through lowered production due to this loss of heat. A lining of low-heat conductivity is more necessary in an electric furnace than in a fuel-fired one, so the lining is usually thicker than in fuel-fired furnaces of similar size for this reason.

But if an electric furnace is to be used only, say, 9 or 10 hours per day, the heat storage in a thick lining may be too great. The inside of the furnace lining must be heated up to or above, depending on the type of furnace, the pouring temperature of the metal before the metal can be poured. The temperature varies through the lining from inside to outside. Now, if the refractory has too high a heat conductivity, the lining must be heated nearly to this temperature for quite a distance back before it ceases to drain the heat away from inside, and before the inside gets up to full operating temperature. In some furnaces having great wall area in comparison to their metal capacity, huge amounts of heat must thus be drained from the inside and stored in the walls during the first two or three melts of the day. This heat leaks away through the furnace shell when the furnace is idle nearly as fast as it does while the furnace is running until the lining gets pretty well cooled off, so the next morning the walls have again to be supplied with the heat they have lost through the night. On continuous operation the walls get "soaked full of heat," or the furnace has reached the "steady state," so that each heat comes out in the same time, and the energy supplied is used in useful work or is lost through radiation from the walls during the heat rather than in heating up the walls. On 9-hour operation on the first few heats of the morning it is necessary to supply not only the shell losses during that heat, but also energy to make up for the shell losses of the night before.

High heat storage therefore means low production and low thermal efficiency when the furnace is not run continuously. It might conceivably pay to make a furnace lining, say 2 inches thick and, if necessary, to water-cool the outside to keep the lining from melting on a furnace to be run but a few hours per day. If one lost an average of 20 kw. per hour for 24 hours with a thick lining, he has to supply 480 kw. h. in whatever time the furnace is run, say, 8 hours, 320 kw. of this being stored and lost at night. He could lose 30 kw. average per hour for 8 hours, and if the furnace had a storage of only 100 kw. h. he could not lose more than that in the remaining 16 hours,

or a total of 420 kw. h. He would then start with a dead cold furnace each morning, but he would be 60 kw. h. ahead on his day's run. St. John³³ has shown several diagrams of the distribution of heat losses which bring out the important rôle played by stored heat.

It is the stored heat lost at night that cuts a large percentage figure in a small furnace and that prevents the usual types of externally heated crucible furnaces from having any chance of commercial usefulness. The lack of stored heat, due to the need for only a very thin heat-insulating wall, makes the high-frequency furnace with its internally heated crucible a possibility for intermittent work in small-sized furnaces.

The inside of the lining must be refractory enough not only merely to resist fusion but to stand up against the atmosphere, the metal, or the slag with which it is in contact.

But the most refractory materials commonly available have a high heat conductivity and a high specific heat; that is, they tend to give both high wall losses and high heat storage. If only such a thickness of this high-temperature refractory be used as will keep the temperature at its back down to some lower temperature at which some other less refractory material of lower heat conductivity and heat storage will stand up, the second refractory then becomes a better material for that layer of the lining than the first.

Past a certain thickness of the second refractory, a third material, still less refractory but of even higher resistance to heat flow and of lower heat storage capacity, then surpasses the second. Even more layers could be used.

Still better would be a brick that varied in composition and properties from one end to the other, as too many layers of very thin bricks give mechanical instability. Some distinct progress is being made in the experimental production of such bricks, especially carborundum fire-clay mixtures.

Nearly all electric furnaces use at least two layers of refractory material. The outside layer next to the shell is the easiest to select, as infusorial earth like "Sil-o-cel" and similar infusorial earth products have in high degree just the needed properties. Heavy asbestos sheets or asbestos cement are sometimes used.

A low-grade fire brick usually fills fairly well the requirements for the middle layer, but the inner layer is the real problem. Most electric brass furnaces use high-grade fire brick, especially those high in alumina. Some use silica brick. On account of the danger of spalling due to heating and cooling, which is shared by magnesite and silica, these materials are seldom used in furnaces for intermittent operation. Carborundum brick has been used in roofs and

³³ St. John, H. M., Commercial testing of metallurgical electric furnaces, *Chem. and Met. Eng.*, vol. 21, 1919, p. 388.

heating troughs. Its heat conductivity is rather high for use in the body of the furnace, though it finds some use for that purpose. Carborundum brick, especially the bonded type, has great resistance to spalling and abrasion. Hartmann and Kohler³⁴ show some striking photographs which bring out clearly the superiority of such brick, as well as of high-grade fire brick, as to spalling on cooling rapidly from 1350° C. over silica or magnesite brick, which spall very badly.

Chromite brick is of doubtful value in the furnaces that have a strongly reducing atmosphere, as it tends to be reduced into ferrochrome.

Zirkite brick, made from crude zirconia ore, is tantalizingly close to being a valuable refractory, but its price is too high to be justified until its properties are improved. When pure zirconia refractories become available they bid fair to give a most desirable combination of properties.

Alundum, or electrically fused alumina bricks, also have possibilities, though they are expensive and are not yet developed very far except for laboratory use.

Alundum cement, however, is of great value in some parts of some electric brass furnaces because of its combination of refractoriness, good bonding power, and its ability to remain an electrical insulator at temperatures at which other refractories become conductors.

Carborundum and alundum are, and pure zirconia refractories probably will be, themselves electric furnace products.

As laboratory experiments and still more important plant tests with improved refractories proceed, the life of electric furnace linings should be greatly improved, and relining costs per ton lowered. It is also hoped that a lining for the induction type can be found to allow that type to handle highly leaded alloys.

The makers are working with refractories of the type used for making graphite crucibles, with some hope of success.

Small amounts of heat may be theoretically saved by painting the furnace shells with aluminum paint or even by nickel plating them, as good reflectors lose less heat than dull black materials. Such a bright finish improves the appearance of a furnace and probably saves a few kw. h., as long as it stays bright, which is seldom very long in a foundry.

In comparing furnaces on the data so far available, preparatory to making a choice for installation in a given plant, the purchaser must consider the ability of the various furnaces to meet the plant conditions imposed, and the suitability of the furnaces as a load on the generating station that will supply the power.

³⁴ Hartmann, M. L., and Kohler, J. F., Physical characteristics of specialized refractories, *Trans. Am. Electrochem. Soc.*, vol. 37, 1920, pp. 349, 355.

CENTRAL STATIONS AND THEIR RELATION TO THE BRASS INDUSTRY.

Few brass foundries or small rolling mills are likely to extend their own generating stations, if they have any, but are more likely to buy their furnace power from a central station when they install electric furnaces. Hence the interest of the central station in electric brass furnaces as a means of extending their service is and should be keen. Not a little of the progress made in electric brass melting so far is due to the work of the central stations, although there are many central stations that have so far neglected the electric furnace as a load builder. Generally, however, the central station is glad to cooperate with the foundry and to have its engineers aid the foundrymen in the selection of a suitable furnace and in its proper installation.³⁵

A wise plan, followed by the more progressive stations, is to assign an engineer or group of engineers to specialization on electric furnace problems as they affect the central station. A little advice given by an electrical engineer of its staff, competent to handle the problems put up to him by the foundry, may result in the connection of a furnace or group of furnaces to the power company's lines, aggregating a kilowattage that it would take a good many installations of lights and motors to equal, and giving a load with a higher load factor and greater general desirability than the average industrial load.

As the central station is the usual source of power, it is of interest to note that the price of power varies with the amount used, so that under one condition the cost per kw. h. may be very different from that under other conditions in the same plant.

VARIATION IN COST OF ELECTRIC POWER.

Industrial power contracts usually have two factors, the demand charge and the energy charge. The first pays the power company for the equipment it must maintain to supply the maximum power needed; the second depends on the total amount of power used.

Suppose we have a maximum demand of 300 kw. and that the average power consumption per ton of metal is 335 kw. h. per ton on 9-hour operation, 275 on 18-hour, and 250 on 24-hour; the total power used per day is then about 2,000, 3,565, or 5,250 for the three cases. In a 25-day month this means 50,000, 91,000, 130,000 kw. h. per month.

Assume that the plant, before it installed its electric furnace equipment, had a maximum demand in lights and motors of 200

³⁵ Compare St. John, H. M., Commercial testing of metallurgical electric furnaces, *Chem. and Met. Eng.*, vol. 21, 1919, p. 377. Editorial article, Some practical data on operating electric brass furnaces, *Elect. Rev.*, vol. 76, 1920, p. 215. Wilcox, E. A., Electric furnace power from the standpoint of the central station, *Trans. Am. Electrochem. Soc.*, vol. 37, 1920, p. 589. Smith, A. C., The electric-arc melting furnace and the central station electric company, *Trans. Am. Electrochem. Soc.*, vol. 37, 1920, p. 701.

kw., and use 20,000 kw. h. per month for those purposes. Taking a concrete case where the power contract calls for a demand charge of \$1.50 per kw. per month for the first 50 kw. and \$1 per kw. per month for all over 50 kw., the energy charge schedule is: 2,500 kw. h. per month at 2 cents per kw. h.; for the next, 3,500 kw. h. per month at 0.8 cent per kw. h.; for the next, 310,000 kw. h. per month at 0.5 cent per kw. h.; all over 347,500 kw. h. per month at 0.4 cent per kw. h.

The 200-kw., 20,000-kw. h. lighting and motor power cost as follows:

$$\begin{array}{r} 50 \times \$1.50 = \$75.00 \\ 150 \times 1.00 = 150.00 \\ \hline \end{array}$$

225.00 Demand.

Total, \$415 or 2.07½ cents per kw. h. used.

$$\begin{array}{r} 2,500 \times \$0.02 = \$50.00 \\ 17,500 \times 0.008 = 140.00 \\ \hline \end{array}$$

190.00 Energy charge.

The plant now has 500 kw. maximum demand and 70,000, 111,000, 150,000 kw. h. used per month on three assumptions.

$$\begin{array}{r} 50 \times \$1.50 = \$75.00 \\ 450 \times 1.00 = 450.00 \\ \hline \end{array}$$

525.00 Demand.

$$\begin{array}{r} \text{Energy—Case 1} \dots\dots\dots 2,500 \times \$0.02 = \$50.00 \\ 35,000 \times 0.008 = 280.00 \\ 32,500 \times 0.005 = 162.50 \\ \hline 70,000 \end{array}$$

492.50 Energy.

525.00 Demand.

1,017.50 Total charge.

Less 415.00 Previous charge for lights and motors.

602.50 Total charge for electric furnace power.

$$\begin{array}{r} \$602.50 \\ \hline 50,000 \end{array} = 1.205$$

The electric furnace power costs 1.205 cents per kw. h.

Case 2. There is the same demand charge, but the energy charge is—

$$\begin{array}{r} 2,500 \times \$0.02 = \$50.00 \\ 35,000 \times 0.008 = 280.00 \\ 73,500 \times 0.005 = 367.50 \\ \hline 111,000 \end{array}$$

697.50 Energy.

525.00 Demand.

1,222.50 Total.

Less 415.00 Lights and motors.

807.50 Total charge for furnace power.

$$\begin{array}{r} \$807.50 \\ \hline 91,000 \end{array} = 0.89$$

The furnace power costs 0.89 cent per kw. h.

Case 3-----	2,500×\$0.02 =	\$50.00	
	35,000× 0.008=	280.00	
	112,500× 0.005=	562.50	
	150,000	892.50	Energy.
		525.00	Demand.
		1,417.50	Total.
Less		415.00	Lights and motors.
		1,002.50	Total change for furnace power.

1,002.50

=0.79.

130,000

The furnace power costs 0.79 cent per kw. h.

Case 4. If the plant had three times the furnace installation figured above and used it 24 hours a day, or 900-kw. furnace demand (1,100 kw. total); 450,000 kw. h. per month furnace energy (470,000 total), the charge would figure:

50×\$1.50 =	\$75.00	\$2,370.00	Energy.
1,050× 1.00 =	1,050.00	1,125.00	
	1,125.00	Demand	3,495.00
			Total.
2,500× 0.02 =	50.00	Less	415.00
35,000× 0.008=	280.00		Lights and motors.
310,000× 0.005=	1,550.00		
122,500× 0.004=	490.00		3,080.00
470,000			Total for furnace power.
		2,370.00	Energy.

3,080.00

=0.685

4,500.00

The electric furnace power costs 0.685 cent per kw. h.

Tabulating these we get:

Case No-----	1	2	3	4
Hours -----	9	18	24	24
Number of furnaces-----	1	1	1	3
Kw. h. per ton-----	335	275	250	250
Power price, cents per kw. h-----	1.205	0.89	0.79	0.685
Cost per ton for power-----	\$3.92	\$2.45	\$1.98	\$1.71

This table shows the advantage of continuous operation of electric furnaces, as well as that of large installations. The exact figures will vary in each particular case, but the ratios will remain approximately the same.

The methods of determining the maximum demand vary in different localities. Often there is a penalty, a higher demand charge if the power factor is below a certain figure, usually 70 per cent. and sometimes a premium if it is over a certain figure. The methods of determining the power factor, for rate-making purposes, may also vary.

It is sometimes possible to obtain a lower rate by buying "off-peak" power; that is, by taking power at any time save for two or three hours per day when the power house has its heaviest load. By suitably arranging the melting schedule, a foundry could sometimes profit by this fact. The peak-load hours are different with different central stations.

Variations in the cost of coal to the power plant are sometimes a factor in the rates paid by the user as well as in the costs of the central station. The schedule of rates should be carefully studied and analyzed before choosing a furnace and in determining the best operating schedule when it is installed.

When electricity is generated by water power, it is bought under schedules somewhat similar to those on which steam-generated power is bought, but the demand charge is usually almost all-important while the energy charge is relatively small. That is, if one's maximum demand is 1,000 kw. it costs nearly as much for power to let the plant lie idle and use no power at all as it does to use 1,000 kw. 24 hours a day. The electrochemical manufacturers at Niagara Falls, for example, strive to keep their average demand just as close to the maximum demand as possible every minute.

The cost of hydroelectric power in this country, to large users who operate 24 hours a day, 365 days a year, as many of the electrochemical industries at Niagara Falls and other similar centers, will probably vary from \$20, perhaps less, to \$40 per kw. year.

Suppose a plant pays \$25 per kw. year and has a transformer capacity of 10,000 kw. It then pays \$250,000 per year for its power, whether at any time it is using the whole 10,000 or none at all.

The ratio of the average load in kw. to the kw. capacity of the plant is called the "load factor." If a 10,000-kw. plant averages only 5,000 kw. actual load, its load factor is 50 per cent and its power cost, when paid for on a kw.-year basis, is twice as much per kw. h. actually used as it would be at 100 per cent load factor. The load factor, therefore, is a most important consideration to electrochemical plants continuously operating. The load factor also plays a part, though not nearly so great a part, in the ratio of the "demand" and "energy" charges of the power bill for steam-generated electric power bought by the small user on a kw.-h. basis. These points are discussed by a number of writers.¹⁶

¹⁶ Holmstedt, C. P., Characteristics of electrical energy as affecting chemical industries, *Trans. Am. Electrochem. Soc.*, vol. 25, 1914, p. 29. Sothman, P. W., Notes on power transmission and transmission economies, *Trans. Am. Electrochem. Soc.*, vol. 25, p. 42, 1914. Fitzgerald, F. A. J., Some economies in the use of energy for electric furnaces, *Trans. Am. Electrochem. Soc.*, vol. 25, 1914, p. 53. Horry, W. S., Power for electric furnace work, *Trans. Am. Electrochem. Soc.*, vol. 25, 1914, p. 59. Longwell, H. E., Power problem in the electrolytic deposition of metals, *Trans. Am. Electrochem. Soc.*, vol. 25, 1914, p. 75. Newberry, F. D., Sources of direct current for electrochemical

Since, on the ordinary price schedule for steam power, the more power is used the lower the rate becomes, so that an extra furnace load added to an existing one really uses less expensive power than the earlier installation used, it is plain that firms who melt both steel and brass and already use electric steel furnaces, are in a favorable position to melt their brass electrically at low cost. Similarly, after a brass and aluminum foundry has turned completely to electric brass melting, the price of the extra power needed to melt also its aluminum electrically may be low enough that the electric melting of aluminum may be more attractive than otherwise.

Berlin,³⁷ has discussed fully the various factors entering into rate schedules. He considers the problem of tandem operation of two furnaces, in order to decrease the maximum demand, one furnace being poured and charged while the other is melting, so that power is only on one furnace at one time. He concludes that it will not pay on steel furnaces. It is possible, however, that it might pay on brass furnaces. One refining plant operating 24 hours per day plans to try running two 1-ton rocking furnaces in this way. Since a 1-ton brass furnace only has to melt about an hour per heat, and it usually takes half an hour to charge and pour, two furnaces thus run would produce 24 tons per day instead of 30 to 32 tons. The power cost per ton will probably not be materially different from that under unrestricted use of both furnaces. As only one transformer will be needed, the first cost of the equipment would be somewhat decreased though not in respect to output. The labor cost is expected to be decreased. Whether this will pay or not can only be told by trial. It would certainly not pay on other than 24-hour operation.

In order to fit the operation of the furnace to the particular schedule on which power is bought, in order to secure power at the lowest cost per ton of product and to operate it to the best advantage, the behavior of the furnace under different operating conditions must be accurately known and is best determined by thorough tests.

TESTING ELECTRIC FURNACES.

A complete test of an electric furnace is as important a matter to the foundry as a complete boiler test is to a power plant. By such a test the possibilities and limitations of the furnace may become very much clearer and better understood.

processes, *Trans. Am. Electrochem. Soc.*, vol. 25, 1914, p. 85. Turnbull, R., Electric furnace regulators, *Trans. Am. Electrochem. Soc.*, vol. 25, 1914, p. 97. Discussion on all of the above, *Trans. Am. Electrochem. Soc.*, vol. 25, 1914, p. 106. Lyon, D. A., and Keeney, R. M., Electrometallurgical industries as possible consumers of electric power, *Trans. Am. Electrochem. Soc.*, vol. 28, 1915, p. 139. Beckman, J. W., The electrochemical possibilities of the Pacific Coast, *Trans. Am. Electrochem. Soc.*, vol. 28, 1915, p. 169.

³⁷ Berlin, W. G., Power problems from the standpoint of the furnace operator, *Trans. Am. Electrochem. Soc.*, vol. 37, 1920, p. 367.

The test resembles a boiler test in many ways, but it may be even more intricate and requires fully as much care. A few plants have made such thorough tests which show the complete distribution of the energy delivered and trace completely the losses of each component of the alloys melted. The tests gave information of value in showing how to operate and to control the furnace in regular practice.

St. John²⁸ has given a complete and useful outline of the way such tests should be conducted. The reader is referred to his article for full information. A few points, however, will be mentioned.

The energy required to melt a given charge depends first of all on the specific heat and heat of fusion of the mixture,²⁹ on its melting point, and how far above the melting point the metal has to be heated. No one would expect to melt Monel metal with as little energy as is required for yellow brass. The nature of the charge also has an effect. Neither all large ingot nor all fine borings will melt as quickly and easily as a judiciously chosen mixture of light and heavy material.

The presence of nonmetallic material, such as sand on gates, may make a great difference in the performance of the furnace, as it may leave a layer of dross or slag over the metal, which in many types of furnaces baffles the flow of heat to the metal and requires more time and more energy to finish the heat. Large amounts of oil make it impossible to close the furnace tightly until it is distilled off, and the soot from its decomposition blankets the charge.

Hence one plant melting a charge of dirty borings and sandy gates, another one of large clean ingot, and a third one of medium-sized scrap, may for an alloy of exactly the same composition in the same type of furnace require quite different amounts of energy. Figures for power consumption, therefore, should be accompanied by a description of the charge.

The pouring temperature is also important. One may cast phosphor bronze into very large gears or into ingots at not much more than 50° F. above its melting point, or one may cast it into small bearings, many on a gate, at 550° F. above its melting point. Smaller variations are met on other alloys, but a smelting and refining plant making ingots only, and a foundry making tiny saddlery hardware or lock parts, will pour their metal at widely differing temperatures.

²⁸ St. John, H. M. Commercial testing of metallurgical electric furnaces, *Chem. and Met. Eng.*, vol. 21, 1919, p. 277.

²⁹ Compare Richards, J. W., The electric power required to melt metals, *Trans. Am. Brass Founders' Assn.*, vol. 4, 1910, p. 95. Clamer, G. H., and Hering, C., The electric furnace for brass melting, *Trans. Am. Inst. Metals*, vol. 6, 1912, p. 95. Hansen, C. A., Electric melting of copper and brass, *Trans. Am. Inst. Metals*, vol. 6, 1912, p. 110. Gillett, H. W., and Norton, A. B., Approximate melting points of some commercial copper alloys, *Tech. Paper 69*, Bureau of Mines, 1913, 10 pp.

Thornton and Hartley⁴⁰ calculate that heating brass to 1,100° C. would increase the gas consumption in a gas-fired furnace 20 per cent over that required to heat it to 1,000° C. Determination of the pouring temperature is essential in comparing the performance of different furnaces on the same alloy or the same furnace on different alloys.

Pyrometers for this purpose are now available⁴¹ and one should be used in every electric brass furnace test of any pretensions to accuracy and completeness.

METERS AND RECORDS.

It is so easy to measure everything one wishes to know about the electric power used in a furnace that there is little excuse for incomplete tests. Every furnace should have at least its individual kw. meter to show the rate at which the furnace is taking power at any moment, and its own kw. h. meter, readable to 1 kw. h. The latter is sometimes left out of the equipment to save its cost, as the central station's kw.-h. meter, on which the power bills are calculated, is supposed to take its place. But this is poor economy, for without a kw. h. meter on each furnace one can not know just how much energy the furnace has used in a given period unless no other load is metered by the same meter. Unless a kw.-h. meter is provided for each furnace, and located on the furnace switchboard, the furnace has to be controlled on a time basis, or by opening it and estimating the temperature of the melt. In most cases far better control is obtained by running on a kw.-h. schedule that has been worked out on the basis of experience, very close temperature control being possible on 24-hour operation, and very good approximations on single-shift operation.

With the induction furnace an ammeter may be substituted for the kw. meter, but the individual kw.-h. meter should be used in that case also. On many types of furnaces a voltmeter and an ammeter for each phase are also required, and a direct-arc furnace might well use power-factor meters also. Graphic meters are of value for permanent records.

The electric furnace, due to the ease of metering, offers, as Miller⁴² points out, every opportunity for the easy recording of operating data, so that if the furnace falls behind its standard performance for

⁴⁰ Thornton, H. M., and Hartley, H., Metal melting, Jour. Inst. Metals (British), vol. 17, 1917, p. 217.

⁴¹ Compare Gillett, H. W., Pyrometers for molten brass and bronze, Trans. Am. Inst. Metals, vol. 8, 1914, p. 340. Editorial, Pyrometers for brass and bronze makers, Chem. and Met. Eng., vol. 21, 1919, p. 114. Kinnison, C. S., An alloy which resists molten brass and bronze, Chem. and Met. Eng., vol. 21, 1919, p. 608.

⁴² Miller, D. D., Electric furnace for heating nonferrous metals, Jour. Am. Inst. Metals, vol. 11, 1917, p. 271.

even a single heat the cause can be sought, found, and remedied more easily than with most fuel-fired furnaces.

METAL LOSS TESTS AND CALCULATIONS.

Metal loss is perhaps the most difficult thing to ascertain in testing any brass furnace, in making records of its operation, or in calculating its money value as an item in melting costs.

In testing the furnace itself the important points are the primary recovery, the percentage of the total weight of metal charged that is obtained in the ladle, the secondary recovery from the slag or dross, and the net loss. Also, how does the value of the primary recovery, the secondary recovery, and the net loss compare with that of the original charge?

For a complete answer both the total weight and the composition of the original charge, the metal in the ladle, and the amount of the secondary metal recovered must be known in order that the net loss—the metal which is gone and can neither be weighed nor analyzed—may be known accurately.

Various conditions often make it hard to attain the desired accuracy. If the charge contains sandy gates or oily, dirty borings it is difficult to be sure that a sample of either used for the determination of the nonmetallic materials is representative, and such a determination is often only an approximation.

On a hearth-type furnace one has to contend with an absorption of metal, often a preferential one as to lead, for example, in a fresh hearth. There is sometimes slight retention of metal in the hearth from heat to heat, requiring great pains in scraping out the furnace and taking up time that would not normally have to be taken when making successive heats on the same alloy. Extra pains to get accurate figures on metal loss may thus delay the operation of the furnace and influence its production and power consumption figures, thus sacrificing accuracy on that part of the test. To get really accurate figures, a metal loss test on a hearth type furnace should extend over a considerable number of heats.

All spill and spatter in pouring must be collected and weighed up for each heat. When the metal is in the ladle the question arises as to how it should be weighed, whether by difference between weights of empty and full ladle,⁴³ which involves inaccuracy in the weighing of hot objects and requires care lest slag, dross, and skulls be weighed as something they are not, by pouring into ingots and weighing those plus the pouring spill and spatter, which means that in a sand-castings shop the metal can not go into regular production, or by weighing as castings, in which case difficulties arise due to the necessity

⁴³Compare Tookin, R. Stand for checking melting losses, Foundry, vol. 45, 1917, p. 20.

for keeping all the castings, gate, spill, and overmetal from a heat together, and to the presence of adhering molding and core sand if the rough castings are weighed or to the loss of metal in cleaning up if the cleaned castings and gates are weighed.

Metal loss figures obtained by comparing metal bought with product shipped, though valuable for cost accounting, do not show furnace performance, for they include the remelting of gates and defective castings.⁴⁴

Pouring into ingots undoubtedly gives the most accurate figure.

Some people, like Collins,⁴⁵ prefer to calculate their metal losses from chemical analysis. Such calculation is a useful check when analysis is to be made anyway, but it is cheaper, and in general, far more accurate, to weigh in the ladle than to analyze. Particularly with furnaces that do not mix the metal automatically, calculation from analysis is unsafe, as there is danger of segregation in the molten metal. Added to that is the possibility of further segregation in the solid metal with attendant possibility of nonrepresentative sampling. On top of these is the inaccuracy of chemical analysis; it takes only a difference within the ordinary analytical limits of error to calculate to a material difference in weight. St. John⁴⁶ points this out and shows that though chemical analysis is useful in checking up the value of the lost metal, to calculate metal losses wholly on analysis involves the fallacy that none of the element used as a basis for the calculation, usually copper, is lost; the fact is, some copper is really lost by oxidation and slagging. This loss may be very little in an electric furnace, but it may be greater in an open-flame oil furnace with which the electric is being compared as to metal losses.

This whole matter has been rather thoroughly discussed,⁴⁷ and it has been shown that while some mills charge up metal loss as having the same value per pound as the charge, and others charge it up at the value of zinc only, neither is correct, the lost material being made up of all the constituents of the alloy, with the more volatile ones preponderating.

The volatilization loss in a fuel-fired furnace is largely zinc and lead and could be mostly made up by the addition of more zinc and lead. It is not fair to the fuel-fired furnace, therefore, to charge it with the full price of the alloy. Neither is it fair to the electric fur-

⁴⁴ Compare Walter, C. M., Metal melting by high pressure gas: *Jour. Inst. Metals* (British), vol. 17, 1917, p. 197.

⁴⁵ Collins, E. F., Melting some nonferrous metals and their alloys in the electric furnace: *Jour. Cleveland Eng. Soc.*, vol. 11, 1919, p. 311.

⁴⁶ St. John, H. M., Commercial testing of metallurgical electric furnaces, *Chem. and Met. Eng.*, vol. 21, 1919, p. 384.

⁴⁷ Discussion on paper by Guenther, E. B., Use of producer gas for melting yellow brass: *Trans. Am. Inst. Metals*, vol. 8, 1914, p. 320.

nance to assume that all the metal saving it shows over the fuel-fired furnace is cheap zinc and lead, when some of it may be copper and tin.

Complete data on losses by weight and on the composition of the lost metal must be obtained if the figures on the value of the metal lost or saved are to be truly accurate.

In considering the metal savings of the electric furnace one must take into account the fact that not only is the net loss usually reduced, but the gross loss is also generally reduced. In fuel-fired practice metal spilled into the ashes or running out of a pot broken in the fire and that entrained in the heavy slag of most open-flame oil furnaces has to be recovered. This metal must be charged with the cost of its recovery and of its remelting if it is pure enough to be remelted direct, and must be charged with the cost of the bad effect of any harmful impurities it picks up.

If it is not suitable for remelting, but must be refined after its recovery and concentration, it must bear the refining charge. In this last case often the only metal recovered after refining is a low-grade copper, all the other metals having been lost.

One brass mill on a run of $14\frac{1}{4}$ tons of 68 per cent copper, 32 per cent zinc in pit fires, had a gross loss of 4.5 per cent, recovered 3.1 per cent from the ashes, giving a net loss of 1.4 per cent. This run was made in 1917 when metals were very high, copper being figured at 30 cents and zinc at 14 cents, making a pound of the brass cost 24.9 cents for its contained metal. The 3.1 per cent of recovered metal was valued by this mill at this time at only 16 cents per pound, after paying recovery charges, so that the drop in value was 7.9 cents per pound, or 24.5 cents per 100 pounds melted.

The money loss from the deterioration and cost of recovery of the recovered metal was, then, greater than the value of the net loss taken as all zinc, and 70 per cent as much as the value of the net loss if this were taken as composed of the same proportion of copper and zinc as the alloy itself.

Several other mills operating crucible fires on yellow brass calculate that in coke-furnace practice $1\frac{1}{2}$ per cent of the charge is spilled into the ashes, and of this 60 per cent is recovered—that is, 0.9 per cent of the original charge is recovered and 0.6 per cent is lost. This 0.9 per cent recovered is said to be worth only 75 per cent of the value of its copper content and, besides, must be charged with the cost of its recovery.

On the basis of the value of the liquid metal obtained ready to pour, the electric furnace generally shows as much money saving due to its lower gross loss as it does due to its lower net loss. Both savings effect real conservation.

ELECTRIC BRASS FURNACES AS A FACTOR IN NATIONAL CONSERVATION.

There are many points in which electric brass melting deserves consideration as a factor in national conservation, and it is its importance as such a factor which has drawn and held the attention of the Bureau of Mines to the general problem.

METAL SAVINGS.

As has been shown above, the electric furnace effects material saving of the metals melted, both by reduction of the net loss and of the gross loss. The possible saving, when the brass industry adopts electric melting as the standard method, will be well worth while, even though the country's resources are large in all the metals, except tin, that enter into brass and bronze. The labor and the transportation facilities required for the production of some 6,000 tons of metal that could be saved by electric melting could then be applied to other needs.

SAVING OF CRUCIBLES.

The avoidance of crucibles not only cuts out a large item of expense but helps to make the United States independent of Ceylon graphite and Klingenberg clay, the shortage in which was so acute during the war that the Bureau of Mines took up the study of the domestic supply of crucible graphite and clays.⁴⁸ The carbon and graphite electrodes and other furnace parts required are made from domestic sources, as graphite electrodes are best made of artificial graphite, itself an electric furnace product.

SAVINGS IN LABOR AND HEALTH.

The reduction of the amount and severity of the labor required and the improvement in the health and safety of workmen due to the comparative coolness and freedom from deleterious fumes and to a reduction in the hazard of burns are as truly conservation as are the more material factors.

SUBSTITUTION OF FUELS.

It is in its bearing on that part of the conservation problem relating to fuel that the electric brass furnace is perhaps of the greatest ultimate importance.

Even under existing conditions, for the electric furnace to use steam-generated power helps the fuel situation to some degree, as it allows the substitution of bituminous coal, burned in the power plant, for coke, anthracite coal, or fuel oil, burned direct at the foundry in

⁴⁸ See White, U. B., *Principal investigations of the Bureau of Mines*, Mimeographed report, June, 1919, pp. 14-26.

fuel-fired furnaces. It is true that in present steam-plant practice the by-products of bituminous coal useful for dyes, explosives, and fertilizers are not recovered; but, as Rideal⁴⁹ points out, these can be saved if the steam plant goes through the producer-gas step and enters the by-product chemical industry.

This question, however, has been investigated by the British Ministry of Munitions,⁵⁰ and the conclusion is reached that under present British conditions by-product recovery is not economical.

At any rate, there is a saving in distribution between the shipment of coal to a large central station and the distribution thence of electric power to foundries, over the shipment of foundry fuel to each foundry, with the trackage, switching equipment, and tying up of rolling stock involved.

SUBSTITUTION OF OIL.

Of real importance is the substitution of steam-generated electric power for direct oil-fired furnaces. Great as are our oil resources they are all too small for the imminent future demands upon them for gasoline, lubricants, and especially for fuel for the Navy and merchant marine. The oil-burning ship, whether it burns oil to raise steam or uses it in Diesel-type engines, is the modern ship. The Navy must have oil and the merchant marine should have it. Just as the electrification of railways could reduce the need for the oil-burning locomotive, so the electrification of brass furnaces could cut down the need for oil-fired furnaces.

Folsom⁵¹ points out that to supply our new merchant fleet it is imperative that the consumption of oil on land be reduced.

The Director of the United States Geological Survey says:⁵²

The position of the United States in regard to oil can best be characterized as precarious. * * * The new demand of our shipping program alone involves fuel oil in quantities equivalent to nearly one-half of the present domestic output. A country-wide thrift campaign needs to be waged. * * *

The last 100 years has resulted only in the exhaustion of less than 1 per cent of the country's coal resources, while in the 60 years since our oil production began 40 per cent of the available oil has been brought to the surface and consumed.

The former Director of the Bureau of Mines⁵³ also pointed out the seriousness of the domestic oil situation.

⁴⁹ Rideal, E. R., *Industrial electrochemistry*, 1919, p. 19.

⁵⁰ Report to British Ministry of Munitions, Direct firing and by-product power production, *Iron Age*, vol. 105, 1923, p. 1234.

⁵¹ Folsom, D. L., Fuel oil for ships after the war, *Am. Inst. Mining Eng., Bull.* 144, December, 1918, p. 873. Rear Admiral Lomas, British Navy, quoted in *Eng. Min. Jour.*, vol. 194, 1920, p. 246.

⁵² Smith, G. C., A foreign oil supply for the United States, *Mining and Metallurgy*, No. 137, January, 1920, sec. 4.

⁵³ Manning, Van H., International aspects of petroleum industry, *Mining and Metallurgy*, No. 138, February, 1920, sec. 24.

A careful analysis of the situation has been made by Gilbert and Pogue,⁵⁴ and they conclude that the sooner the enlarging use of fuel oil for steam raising and heating be turned into a narrowing use the better.

It seems evident that the substitution of oil by coal-generated electric power is a move in the right direction.

SAVING OF COAL.

By reason of the efficiency of the electric furnace, it is possible also to effect a saving in the actual number of heat units required to melt a given amount of metal.

If the power is generated either from coal, through a steam boiler and turbo-generator, or through a gas producer and gas engine, from gas tar through a Diesel-type engine and generator in a reasonably efficient, large, central power plant, the efficiency of the thermally more economical of the available electric furnaces, if properly operated, is so good that electric melting may require fewer B. t. u. in the power plant fuel than would be needed for melting in fuel-fired furnaces.

The most modern central stations can deliver to their customers 1 kw. h. for 25,000 B. t. u.—that is, the equivalent of 2 pounds of bituminous coal. Three pounds of coal may be taken as an average figure when less efficient central stations are included,⁵⁵ although both lower and higher figures are taken by various authorities.⁵⁶

In crucible-pit fires, 600 pounds of coke per ton of yellow brass melted, or 800 pounds per ton of red, is fair practice; that is, if yellow brass is melted at 200 kw. h. per ton and red at 265 kw. h. per ton, each kw. h. being generated by 3 pounds of coal, no more fuel is used than would be with direct firing.

It has been shown that these figures can be reached on 24-hour operation on the alloys to which they are fitted by the larger sizes of direct-arc, stationary, and moving indirect-arc, and by induction furnaces, each furnace being, of course, used on alloys to which it is

⁵⁴ Gilbert, C. G., and Pogue, J. E., *Petroleum, a resource interpretation*: Smithsonian Institution, U. S. Natl. Museum, Bull. 102, part 6, 1918; compare Rice, G. S., *Review of the coal situation of the world*, Bull. Am. Inst. Min. Eng., 133, 1918, p. 131. Arnold, R., *Conservation of oil and gas resources of the Americas*, Econ. Geol., vol. 11, 1916, pp. 203, 299. Requa, M. L., *Petroleum resources of the United States*, Sen. Doc. 363, 64th Cong., 1st sess., 1916. U. S. Navy, *Oil conservation, a national necessity*, Ann. Rept. Sec. of the Navy, 1916, p. 33. Dunn, F. B., *Industrial uses of fuel oil*, 1916. Editorial note, *Crude oil imports set up a new record*, Foundry, vol. 48, 1920, p. 293; Editorial note, *Fuel oil Prices*, Iron Age, vol. 105, 1920, p. 1101.

⁵⁵ Compare Benzinger, R. F., *Solving the ever-increasing cost of central-station operation*, The Electric Furnace, vol 1, No. 2, p. 16. Cook, C. S., *Power production for electrochemical purposes*, Trans. Am. Electrochemical Soc., vol. 35, 1919, p. 67.

⁵⁶ Compare Report to British Ministry of Munitions, *Direct firing and by-product power production*, Iron Age, vol. 105, 1920, p. 1234. Volgesang, A. T., *St. Lawrence power*, Power, vol. 51, 1920, p. 397. Report of Committee, Am. R. R. Assn., *Mining and Metallurgy*, No. 161, May, 1920, p. 7.

fitted. They can probably not be reached by even the more efficient of the reflected-heat furnaces.

In a locality where the central station was so shortsighted as to disregard the advantages to itself in an electric furnace load, and to accept the tentative suggestion of an editorial in a recent electrical journal⁴⁷ that the value of the service rendered by electric furnaces was so high that they could stand being charged rates "approximately those for lighting service" (if the public service commission of the State did not, as it probably would, prevent the charging of such an unjust rate), the combination of high rates and an inefficient furnace would soon cause its user to change to a more efficient type or to go back to fuel-fired furnaces, just as happened in a steel foundry. This plant was using a Heroult electric furnace for steel castings, but when the cost of power rose to nearly 2 cents per kw. h.,⁴⁸ the electric furnace was sold and an open-hearth installed. The power cost was the item that necessitated the change, even at the expense of a slightly less high quality of steel, the open-hearth steel, in this case, being of good enough quality for the purpose in hand.

Whether or not economic conditions will allow the use of an inefficient furnace, on account of the need of fuel conservation, it is a waste to utilize a furnace less efficient in the use of electric power for any certain purpose where a more efficient one as to the use of power will do the work at as low an over-all cost to the user. The less efficient of two electric furnaces may show a great reduction in melting cost over the old fuel-fired furnaces, but with equal melting costs in the two motives of conservation should lead to the choice of the more efficient furnace.

For this reason special stress has been laid in this report on the difference in performance as to power consumption per ton of different types of furnaces, and with different methods of operation. It is true that as far as a cost sheet goes other advantages may sometimes make up the difference between a furnace melting at 300 kw. h. per ton, and another at 450 kw. h. per ton, but the balanced costs fail to indicate that the first uses but two-thirds as much as the second from the Nation's coal pile. In reference to desirability of economical utilization of coal, see Gilbert and Pogue.⁴⁹

WATER POWER.

Generally speaking, the brass industry in this country is at such a distance from developed water power or from that likely to be developed in the near future, that the general utilization of hydro-

⁴⁷ *Electric Furnace Notes*, *Electrical World*, vol. 75, 1920, p. 767.

⁴⁸ *Melting Brass by Electric Power*, *Foundry*, vol. 48, 1920, p. 253.

⁴⁹ Gilbert, C. B., and Pogue, L. E. *Coal, the resource and its full utilization*: Smithsonian Institution, C. B. N40. *Museum, Bull.* 102, part 4, 1918.

electric power for brass melting will have to be accomplished by the location of new plants within economical transmission distance of existing or future water-power development, or by the tying-in of water power and steam plants into a large network or such "super-power system" as has been advocated by former Secretary Lane.⁶⁰

Murray calculates⁶¹ that though the investment required by the proposed superpower network would be \$1,250,000,000, including the cost of changing from steam to electricity in railroads and industrial plants, it would return 24 per cent on the investment. It seems inevitable that this great improvement will sooner or later be made.

Another power project that may develop in the future is that on the St. Lawrence River, the main idea being to deepen the river to allow passage of seagoing vessels. Hoover⁶² cites this project as being "entirely feasible," capable of relieving the railroads from their peak load, and estimated to save 5 to 6 cents per bushel on the transportation of grain. In such a development a large amount of hydroelectric power would be made available, which would be free from the seasonal variations of some hydroelectric projects on account of the natural storage of the great lakes. Vogelsang⁶³ estimates that the power available as the United States share of that developed would be equivalent to 9,750,000 tons of coal per year and would require nearly 8,000 fewer workmen in the hydroelectric plants than would be required to develop the same power by steam.

With such huge projects as these in the East adjudged feasible and desirable by eminent engineers and economists and the advance of the already large hydraulic developments in the West, adequate electric power supply seems bound to come in the future.

Until hydroelectric power is thus made available electric brass furnaces will continue to utilize steam-generated power in the great majority of cases in this country.

Some other countries, though they do not melt much brass compared to the United States, will probably be able to apply hydroelectric power to brass melting when they start to utilize the electric brass furnace.

Sweden and Norway⁶⁴ have long been noted for their hydroelectric developments, which were forced upon them by the scarcity

⁶⁰Anonymous, Secy. Lane's proposal for power resource survey: *Elect. World*, vol. 73, 1919, pp. 282, 331; see also Report of Committee of Am. R. R. Assn., Mining and Metallurgy, No. 161, May, 1920, p. 7; Murray, W. S., Superpower Survey report: U. S. Geol. Survey Prof. Paper 123, 1921, 261 pp.

⁶¹Murray, W. S., Economical power: *Jour. Am. Inst. Elect. Eng.*, vol. 39, 1920, p. 27; Economical supply of electric power for the railroads and industries of the North Atlantic seaboard: *Jour. Am. Inst. Elect. Eng.*, vol. 39, 1920, p. 219.

⁶²Hoover, H., Some notes on agricultural readjustment and the high cost of living, *Sat. Eve. Post*, vol. 192, 1920, Apr. 10, p. 46. See also Craig, C. P., From the Great Lakes to the Atlantic, *Sat. Eve. Post*, vol. 192, 1920, June 26, p. 40.

⁶³Vogelsang, A. T., St. Lawrence power: *Power*, vol. 51, 1920, p. 397.

⁶⁴Compare Beckman, J. W., Power developments in Scandinavia, *Trans. Am. Electrochem. Soc.*, vol. 37, 1920, p. 403.

of fuel, and for their application of electric furnaces to the iron industry.

Italy has a highly developed water-power system, and there is to-day⁶⁴ a larger production of electric steel in Italy than of Bessemer steel.

In 1920 France⁶⁵ was expected to utilize about 1,600,000 h. p., or twice what she utilized in 1913. According to Keller,⁶⁷ the various plants of Keller Leleux and the Government plants designed by Keller were using electric furnaces on war production of pig iron, steel, carbide, etc., requiring about 30,000 kw., most of which was from water power.

The situation as to electric power in England has not been good, there being practically no water power, and according to Rideal⁶⁸ the average of some 600 power stations being only 5,000 h. p., or, as he states, one-quarter the size of an economical generating unit and one-thirtieth of the size of a really economical central station. Centralization into larger units is contemplated.

The fuller utilization of our own water-power resources has long been recognized as desirable and in the near future necessary.⁶⁹

The long-delayed constructive legislation which will make this a certainty for the future is now in operation, although on account of the large capital investment and the time required to construct hydroelectric plants some years will elapse before the full benefits can be realized. Comparatively prompt increase in utilization of water power is nevertheless assured.

OPERATION OF ELECTRIC BRASS FURNACES.

When cheap hydroelectric power becomes generally available for use with electric brass furnaces in this country in the future the economical use of power may become subordinate to other points in furnace operation, but as long as electric power is relatively costly the selection and operation of a furnace must take into account the fact that the power bill is one of the largest items of melting cost. How to operate with a low-power consumption, how to increase production, keep upkeep and repair cost down, and how to hold the metal losses low and the quality of the product high are the main questions confronting the electric furnace operator.

⁶⁴ V. D., 1000 fours électriques à acier dans le monde, Jour. du four électrique, vol. 28, 1919, p. 114.

⁶⁵ Toubert, Lt. Comdr., French postwar mineral resources, Mining and Metallurgy, Bull. 157, Jan. 1920, Sect. I, p. 21.

⁶⁶ Keller, C. H., Synthetic electric furnace cast iron, Trans. Am. Electrochem. Soc., vol. 37, 1920, advance copy.

⁶⁷ Rideal, E. K., Industrial electrometallurgy, 1919, p. 15.

⁶⁸ Compare Data, G., The water power situation, including its financial aspect: Trans. Am. Inst. Elect. Eng., 1916, p. 575; Gilbert, C. G., and Pogue, J., Power, its significance and needs: Smithsonian Institution, U. S. Natl. Museum, Bull. 102, part 5, 1918.

To keep the metal loss low and the quality of the product high, the fundamental principle is to choose a furnace that can be run tightly closed, to keep air out and volatile metals in, and then to take care that it is really so run. When the charge contains oily borings it is impossible to operate any furnace tightly closed till the oil is driven out. But the oil vapor prevents the entrance of air as long as it is coming off, so if the furnace is plugged up as soon as the oil is off, little metal vapor is lost, as the bulk of the oil is out before the metal is melted and hot enough to vaporize much of the volatile constituents of the alloy.

Low upkeep and repair cost for refractories depends on the care and attention given the furnace, especially in the matter of overheating the lining or roof. Overheating is mainly due to the use of too high a rate of power input. But the higher the rate of power input the greater the output of product and the lower the energy cost per ton. Careful balancing between these two factors has to be made.

The rate at which the furnace can safely take and the transformers safely supply energy should be properly balanced so that there is enough transformer capacity to allow the furnace to do its best work, but not so much excess capacity as to involve a useless expense for the purchase of too large a transformer. On arc furnaces a balance has to be struck between a power factor that is high enough to make the arc so unsteady as to require too much attention or to make it too easy for the operator to allow the furnace to take too much power, and one so low as to involve waste by requiring larger and more expensive leads or a power factor penalty on the power bill. Automatic electrode control on arc furnaces and pyrometric records of roof temperature in the resistance type aid in allowing the operator to hold the maximum safe rate of input. Automatic electrode control is seldom justified in the installation of a single brass furnace, as it does not often cut the labor cost appreciably. But on a battery of two or more arc-type furnaces automatic electrode control, where it is possible to apply it, will usually pay for the investment very promptly by saving labor.

In order to allow holding the power input up to the maximum rate, the furnace operator must have all the meters to guide him that the particular type of furnace in use requires. Graphic meters and the keeping by the operator of a regular furnace log, showing time per heat spent in charging, melting, and pouring, in waiting on account of outside delays, and delays due to the furnace itself, kilowatt-hours used, weight charged and obtained, electrode consumption, etc., are most valuable in allowing the management to see to it that the furnace is operating properly.

To get a high production with the minimum power per ton one should use a furnace of the largest size his demand for metal will

allow, or that he can take the metal away from promptly, as the larger the capacity of a given type of furnace the more efficient it is. But if a large furnace has to be poured through a number of small ladles, the ratio of idle time to operating time may be so great that a smaller and more quickly emptied furnace may give better results.

On account of the high first cost of the electric furnace its overhead per idle hour is high. Moreover, the furnace while idle is leaking heat from its walls that has to be replaced during the next heat instead of going to the melting of metal. This leakage occurs not only between heats during the day, but at night also, so that there is usually a great difference in the efficiency of a furnace on 9-hour and on 24-hour operation.

The more nearly the furnace operates continuously the more cheaply it will operate. On continuous operation there is far less difference between the power consumption per ton of the more and the less efficient types than there is on 9-hour operation. Two-shift, 16-hour operation shows a greater improvement over one-shift operation than 24-hour over 16-hour operation. If melting costs are a main factor, and the quality of the castings is good with night work, as in rolling mills and smelting and refining plants, the tendency should be toward two-shift operation. In a shop making intricate cored castings in sand, unless artificial illumination can be provided that will keep the defective castings from night work down to the daylight figure, single-day-shift operation will prevail.

In single-shift operation, delays in pouring, waiting for the ladle crane, or holding the metal in the furnace because molds are not ready, operate to the great detriment of high furnace production and low power cost. Of course, melting is only one of the factors in foundry costs, and it may be better in the long run to operate on the basis of molding as the main factor, holding the metal in the furnace to wait for molds if necessary, and fitting the rate of melting to the rate of molding, but it should be clearly recognized that this handicaps a furnace greatly. Even for such operation the electric furnace has advantages; in the types without too great heat storage so that metal held in the furnace does not continue to heat up too rapidly from the heat stored in walls and roof, it is possible to hold the metal longer without damage to its quality than in fuel-fired furnaces.

If metal is to be held in furnaces of high-heat storage after it is ready to pour, additions of cold metal may have to be made to keep the charge from getting too hot before it is poured.

The average foundry using electric furnaces does not appear to realize how a few minutes delay waiting for the next charge, a few minutes more waiting for crane or ladle, and a few more holding the metal waiting for molds may add up in the course of a day to time enough to make another heat. Any furnace will illustrate this fact.

Take an actual day's run of a small Rennerfelt on red brass for example:

TABLE 55.—*Operation of a furnace with and without delays.*

Heat.	Charge.	Total time.	Arc on.	Idle time.	Kilowatt hours used.	Kilowatt hours per 100 pounds.	Notes.
	<i>Pounds.</i>	<i>Hrs. Min.</i>	<i>Hrs. Min.</i>	<i>Hrs. Min.</i>			
1.....	497	2 45	2 44	40	211	42	Furnace at red heat from previous day's run.
2.....	522	1 45	1 25	20	130	25	
3.....	527	2 55	1 10	1 45	105	20	Delay waiting for molds.
4.....	523	1 25	1 05	20	106	20	
5.....	394	1 25	1 10	15	94	25	Waiting for molds, so held power input low.
Total Average	2,463	10 15	6 55	3 20	646	26	520 kilowatt hours per ton.

This could have been run as follows by eliminating all delays:

Hours.	Charge.	Total time.	Arc on.	Idle time charging and pouring.	Kw. h.	Kw. h. per 100 pounds.
	<i>Pounds.</i>	<i>Hrs. Min.</i>	<i>Hrs. Min.</i>	<i>Hrs. Min.</i>		
1.....	525	2 10	1 55	15	215	41
2.....	525	1 40	1 25	15	130	25
3.....	525	1 25	1 10	15	105	20
4.....	525	1 20	1 05	15	100	19
5.....	525	1 20	1 05	15	100	19
6.....	525	1 20	1 05	15	100	19
Total.....	3,150	9 15	7 45	1 30	750	a 24

a Average, or 480 per ton.

The elimination of delays thus gives a 25 per cent increase in output in an hour's less time and decreases the power consumption 40 kw. h. per ton.

The difference between the results of a test run, made to show the maximum performance of the furnace, with everything arranged for rapid operation and those in regular operation under "foundry handicaps" is often very marked, and the maker's guarantees as to furnace performance under proper operation may be far better than the figures on everyday performance if the furnace is not properly operated.

Test runs should always be made and the best possible performance of the furnace determined. If the foundry does not closely approach this performance in regular operation, the manager can figure out how much his failure to provide the furnace with the conditions under which it can best operate is costing him. There is always a point at which rigid putting of the furnace performance first and requiring the other foundry operations to be arranged mainly with respect to efficient melting is more expensive in the long

run, and it is not always best to try to get 100 per cent of the possible performance from the furnace. But the extra saving possible by giving the furnace proper operating conditions and getting high production per furnace is generally large enough to demand consideration, because of high interest charges per ton of product when the expensive electric furnace is not allowed to give maximum production, and of the lowered power cost per ton when production is high.

It is, then, of greater relative importance among all the different foundry operations that an electric furnace be operated under conditions as favorable as possible to it than in the case of fuel-fired furnaces.

VALUE OF MECHANICAL CHARGING.

It saves much time to be able to dump the charge in mechanically from above instead of having to throw or shovel it in through a door in the side or end of the furnace. Such furnaces as the Snyder, the Detroit, and the Ajax that can be charged from the top, if installed with mechanical charging in view, or located so that no craneway or other structure over the furnace renders mechanical charging out of the question offer opportunity for time saving. Other types of furnaces which must be charged by hand through a door should have doors of generous size. If hand-charging must be used, chips, unless in relatively small amount, when they may be useful for charging first to form a cushion to prevent damage to the refractories when charging heavy ingots, may be briquetted,⁷⁰ and bulky material, like wire, should be compressed or "cabbaged."

Generally speaking, the furnace should be at a red heat before the first charge of the day is put in, this being obtained by preheating the empty furnace if it has cooled too far since last used.

The best results are obtained with a tightly closed furnace, and it is usually better to put the whole charge in at once instead of melting part, then opening the furnace to add the rest. If a large amount of cold metal is added to a relatively small mass of molten metal, the solid material may sink in the molten mass and freeze the whole into one solid chunk, which is harder to melt than a piled-up mass of smaller pieces.

Most furnaces should not be opened between charging and pouring, though if the charge contains too much nonmetallic material that may form a blanket of dross or a mirror-like slag, it is sometimes better to open the furnace and skim the slag or dross as soon as the charge is molten, as such a blanket or cover may retard the heating of the metal. Provision of sufficient heated ladles to allow

⁷⁰ Compare Stillman, A. L., Briquetting of nonferrous light metal scrap, Jour. Am. Inst. Met., vol. 11, 1917, p. 193.

emptying the furnace rapidly and the arrangement of ladle hoists and trolleys or craneways so that one ladle can be poured immediately after another, are important factors in time saving.

There are various details in which the operation of special types of furnaces require special procedure. In the Snyder the bottom electrode must be kept in metallic contact with the charge. In the rocking and revolving types care must be taken not to rock too far or to revolve too soon to prevent electrode breakage. In the Baily the furnace must be heated empty at night if run but one shift per day. In the Ajax the charge must be kept poked down and a layer of charcoal kept on the metal to prevent access to air. All furnaces are alike, however, in that the more steadily they are kept at melting and the less time they are allowed to be idle, the better their performance. On all, also, it is desirable that the temperature be controlled as closely as possible that the metal be not heated hotter than it is necessary to pour the casting desired properly. Needless superheat simply wastes time and energy.

PREHEATING THE CHARGE BY FUEL.

It is often suggested⁷¹ that brass melting should be done in two stages, first, heating the metal to a red heat by fuel and then transferring the hot metal to the electric furnace for melting.

Theoretically, this has many advantages. It is well known that the lower the temperature to which material is to be heated the more expensive it is to generate that heat electrically in competition with fuel.⁷² That is, the thermal efficiency of fuel-fired furnaces is the higher the lower the temperature to which their contents are heated. Or it would take fewer B. t. u. to heat brass to, say, 750° C. (1,400° F.) by direct fuel firing than by electric heating, not because the electric furnace is less efficient at the lower temperatures but because the fuel-fired furnace is more so.

If, then, we could preheat the metal by fuel and could charge the hot metal into the electric furnace we would do only that part of the work in the electric furnace which the electric furnace can do most efficiently. We would increase the output of the electric furnace and thus decrease the cost per ton for interest on the investment in the costly electric furnace. Volatilization of zinc and lead from brass is very small indeed until the alloy is melted and superheated; therefore, the metal loss would not be increased. If the

⁷¹ Compare Clamer, G. H., and Hering, C., The electric furnace for brass melting, *Trans. Am. Inst. Metals*, vol. 6, 1912, p. 97. Hansen, C. A., Electric melting of copper and brass, *Trans. Am. Inst. Metals*, vol. 6, 1912, p. 127. Hering, C., Ideals and limitations in the melting of nonferrous metals, *Jour. Inst. Metals (British)*, vol. 17, 1917, p. 250.

⁷² Compare Johnson, W. McA., and Sieger, G. N., Electric furnaces, their design, characteristics and commercial application, *Metal. and Chem. Eng.*, vol. 11, 1913, p. 506.

scheme could be applied to oily borings, the oil would be driven off in the preheating and would not interfere with the operation of the electric furnace.

Only such electric furnaces as are capable of mechanical overhead charging would be suitable for such a process. The success of the scheme would depend on how well the mechanical details were worked out and on whether or not harmful oxidation could be prevented in the transfer of the material from the preheating furnace to the electric furnace.

The synchronizing of another operation to the regular sequence of melting and the extra equipment and attention required would be a drawback, but there are many cases where the scheme would be worth a trial.

In melting cathode copper, if the cathodes can be kept from taking up oxygen or sulphur during the preheat, so that the electric furnace received material which on melting will have the proper composition to give a high-conductivity product, the scheme ought to help the electric furnace in its difficult task of competition with the present huge reverberatory furnaces.

This scheme of preheating the charge is advocated for steel melting by the Industrial Furnace Co., makers of the Snyder furnace, in which the whole roof is removed for charging so that a hot charge could be dumped in readily. No details on the operation of the plan in practice are yet available, but apparatus for such operation is being installed at the Standard Steel Castings Co., Cleveland. A considerable decrease in power consumption and electrode consumption per ton and a corresponding increase in output is expected, test runs on 2½-ton charges of steel that required 600 kw. h. per ton with metal cold, taking but 360 kw. h. per ton when the metal is preheated to a cherry red.

If the same ratio holds in brass melting the power consumption of an arc furnace which melts red brass at 325 kw. h. per ton without preheating and produces, say, 6 tons in 9 hours, would melt at less than 200 kw. h. per ton and would produce about 10 tons if all the charge were preheated.

An induction furnace, melting yellow at 200 kw. h. without preheating and producing some 7 tons in 24 hours, would melt at 120 kw. h. per ton and produce over 11 tons. Clark⁷³ has designed for the Bridgeport Brass Co. a method of preheating for use with the induction furnace, but so far⁷⁴ the ratio between fuel prices and power prices has been such that in the very efficient induction furnace the complications added to the furnace by preheating have outweighed

⁷³Clark, W. R. U. S. Patent 1,328,712 Jan. 20, 1920.

⁷⁴Webster, W. R. Personal communication, Jan. 31, 1920.

the possible saving in cost of power plus fuel over that of power alone, so that the scheme has not yet had experimental test. The less efficient the furnace and the higher the cost of power, the greater the incentive to try out preheating will be.

FUTURE DEVELOPMENT OF ELECTRIC BRASS FURNACES.

There are some points on which the path of progress of electric brass furnaces is fairly clear. Mechanical refinements, use of automatic electrode control in batteries of arc furnace, and a slow but general improvement in life of refractories may be looked for as experience is gained. There are, however, many points of interest on which there is not yet enough collected experience to allow prediction.

Whether the tendency in the use of existing types of electric brass furnaces will be toward the use of small furnaces, pouring 500 pounds per heat or less, or toward the 1-ton or larger furnaces, can not yet be decided. Practice will doubtless differ according to conditions, but just what conditions make one or the other alternative the better are not yet thoroughly clear.

Whether the types of furnaces that are so far doing the bulk of the nonferrous melting will continue to do so, or whether furnaces which so far have not had wide commercial use, or some of the others which are still in the experimental stage, or some brand-new entrant into the field will find large use has still to be seen. Much progress is still to be expected and the furnaces of to-day are doubtless crude compared to those of the future.

Nevertheless, enough progress has already been made so that there are electric furnaces suitable for and commercially successful in melting all sorts of nonferrous alloys. No one type of furnace is "best" for all sorts of nonferrous alloys, but the field is thoroughly covered if the different types are used on that portion of the field each is best fitted for.

The electric furnace has not yet displaced the fuel-fired furnace from the field, nor will it do so completely in the near future, if ever. But it does seem certain that in the great majority of cases the electric melting of brass is both the best and the cheapest method, and that electric furnaces, by their sheer superiority of service, must be ultimately destined for a dominant place in brass melting.

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